SLAMMING OF A SHIP STRUCTURAL MODEL WITH BACKING MATERIAL

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B.S. M.E., Auburn University
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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF NAVAL ENGINEER
AND THE DEGREE OF
MASTER OF SCIENCE IN NAVAL ARCHITECTURE
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at the
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James Joseph Goodwin, U.S.N. and

John William Kime, U.S.C.G.

Submitted to the Department of Naval Architecture and Marine Engineering 22 May 1964 in partial fulfillment of the requirements for the Master of Science degree in Naval Architecture and Marine Engineering and the professorial degree, Naval Engineer.

ABSTRACT

A four ton, one-quarter scale elastic model of the type used in previous drop tests was modified and tested to determine the effectiveness of various backing materials in preventing or reducing slamming damage. Extensive experimental results considered to be excellent data are included.

The model was tested by free-fall drops in tracks onto a water surface. Instrumentation was provided in the central panels to record pressure, deflection, strain, velocity and integrated acceleration time histories.

The records obtained from tests with two backed models were compared with records from tests on an unbacked control model. The records showed that for a backing material to be effective, it must maintain contact with the plating to be protected and be capable of absorbing large amounts of energy when the plating deflects elastically.

Motions of the bottom panels of plating relative to the overall section motion is shown to cause cavitation pressure reloading of the same order of magnitude as the initial pressure experienced on impact.

Recommendations concerning the use of backing materials are set forth.

Thesis Advisor: J. Harvey Evans

Title: Professor of Naval Architecture

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The authors also wish to thank Dr. Donald Ross of Bolt, Beranek and Newman, Inc. for his help in developing the theoretical explanation of the behavior of visco-elastic materials.

The models, carriage and track were built at Norfolk Naval Shipyard. The testing was conducted by the Underwater Explosions Research Division of the David Taylor Model Basin at the Norfolk Naval Shipyard under the direction of the authors. This project was funded by the Structural Mechanics Laboratory, David Taylor Model Basin.

by the Department of Naval Architecture and Marine Engineering, Massachusetts Institute of Technology.

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NOTATION

B = Maximum beam of a ship

c = Damping coefficient

"c" = Speed of sound

c_c = Critical damping coefficient

E_1 = Young's modulus shell plating

E_2^* = Complex Young's modulus of visco-elastic backing material

e = Base of the system of natural logs

e_2 = Relative Young's modulus = E_2/E_1

H_1 = Shell plating thickness

H_2 = Backing material thickness

h_2 = Relative thickness of backing material = H_2/H_1

L = Length between perpendiculars of a ship

m = Mass of shell plating per unit area

p(t) = Pressure as a function of time

p_o = Maximum pressure amplitude

p_{tr} = Transmitted pressure

t = time

v(t) = Velocity as a function of time

$\dot{v}(t)$ = Acceleration as a function of time

W_1 = Weight of shell plating

W_2 = Weight of backing material

$Z = m/\rho c\theta$

η = Loss factor of a composite plate = $2c/c_c$

η_2 = Loss factor of visco-elastic backing material

$\eta_2 E_2$ = Loss modulus

$\eta_2 e_2$ = Relative loss modulus

θ = Decay constant

ρ = Density of water

ρ_2 = Density of backing material

E_2 = Young's modulus of visco-elastic backing material

I. INTRODUCTION

When a ship is making headway into a sea in such a manner that its period of encounter with significant waves of the sea spectrum is equal to its natural period in pitch or heave, a phenomenon known as pounding or slamming occurs. There is much confusion as to what is meant by pounding and slamming. For the purpose of this work, pounding will be defined as the general large pitching and heaving amplitudes caused by near resonance with the sea. Slamming will be taken to mean the violent hydrodynamic shock caused when the ship's forefoot re-enters the sea after a previous emergence.

The most common damage associated with slamming is the "dishing" of plating and the "tripping" of stiffeners in the region of the forefoot of the ship. In some cases slamming will cause a violent longitudinal whipping vibration in the ship. This motion can cause significant damage to the vessel at points remote from the forefoot. This latter type of damage is rather uncommon, and our work will be concerned only with the local slamming damage.

Slamming first became of interest in the 1920's, because the state of technology had become such that it was possible for ships to drive themselves into a sea at a sustained speed which would cause them to resonate in pitch and heave, assuring motions favorable to slamming. The first studies were concerned with ridid body motions and hydrodynamics and wedge

impact studies such as Von Karman's work. [1]* At present, ship motions, the effect of hull form, weight distribution and structural response are the objects of study. These studies are being made with the purpose of finding better design methods for the naval architect and marine engineer.

The work outlined in this paper is an attempt to evaluate the usefulness of backing materials in reducing or preventing slamming damage. The authors have served aboard ships that have experienced severe slamming motions. At no time did local slamming damage result. The authors feel that the backing afforded by fuel oil in tanks in the area of impact helped to prevent such damage. This stimulated interest in the use of backing materials and subsequently lead to the present investigation. It is believed that the results obtained will give an indication of how ships now in operation can be protected from local slamming damage.

A thorough search of the literature reveals that U. S. Coast Guard weather ships of the WAVP class [2] and Dutch destroyers [3,4] have been instrumented and caused to slam in a seaway. Data is available from these tests. Except for the work of Howard [5] and Clevenger and Melberg [6], however, there is at present practically no data available on controlled model slamming tests. There is no indication that any full scale or model tests have been conducted using backing materials. All data from this investigation will be

*Numbers in brackets refer to bibliography.

included in graphs and tables as an aid to future investigators.

A $\frac{1}{4}$ scale model of a section of the bottom of a new Coast Guard cutter was extensively instrumented and loaded with various substances considered suitable as backing material. The bottom section modeled was taken from the region 0.25L to 0.35L from the bow. This is the region where maximum slamming pressures will occur. [4] The width was 0.5B, and the model had a ten degree deadrise. (See Figure I.)

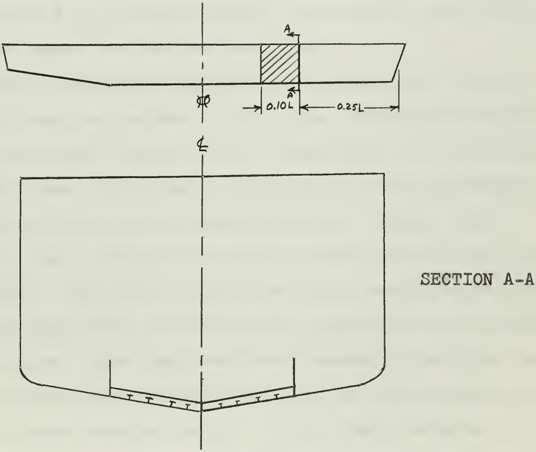


Figure I.

Due to economical considerations it was decided to test two materials in each of two models and to test one unbacked model as a control. [7] Each model was given the same test program, and their weights were kept as nearly equal as possible to make the type of backing material used the only variable.

The models were made almost identical to those used by Clevenger and Melberg, so that the data obtained in these tests would suppliment the very extensive data obtained by these investigators. It was believed also that data obtained in the present tests would be more useful to future investigators if it were obtained from similar models and in a similar manner as the previous data.

Backing materials considered for testing were water, fuel oil, sand and rubber. After some investigation it was found that rubber itself would be unsuitable for this work, but that other visco-elastic materials had been developed which would absorb much larger amounts of energy. The materials were chosen with regard to their practicality on board ship. Water and oil are obviously carried on all ships, and many ships have oil tanks in the area where local slamming damage occurs. Sand was considered because it can also serve as ballast and very probably would not be objectionable in lightly loaded merchant ships. Visco-elastic materials, while not common onboard ship, could be used on any conventional ship that is not weight limited and could be very helpful in special applications. These applications could be to protect

the hulls of planing boats while they were planing in heavy waves. Visco-elastic materials, being lighter than metal, would allow a weight reduction, if successful. The hulls of hydrofoils must be protected when taking off and landing in heavy seas. The lightness of visco-elastic materials would make them ideal for such use.

Another objective of the experiments conducted in the course of this work was to determine, if possible, how the backing materials acted to prevent deformation of the plating which they were backing. A detailed discussion is presented in the theoretical section of this paper.

II. PROCEDURE

It was necessary to build two models of the type used by Clevenger and Melberg [6] to carry out the testing involved in investigating backing material. One model which had not been used by the above investigators was used in this testing program. The additional models were constructed at the U. S. Naval Shipyard, Norfolk, Virginia.

In order to have a good basis for comparison with previous tests, it was decided to keep the material in the new models as nearly identical to that in the original models as possible. The transverse and longitudinal frames and stiffeners were made from the same plate as the original models of Clevenger and Melberg. The bottom plating presented a challenge in that the plating in the original models was of exceedingly low yield strength. The lowest yield steel which could be obtained commercially without heat treatment was used in the new models. To be sure of the properties of the new steel used, coupons were cut from all plates and test specimens were made from these coupons. Using the test specimens the yield strength and Young's modulus of all steel used in the bottom plating were accurately obtained. The results are contained in Appendix A.

The models used were $\frac{1}{4}$ scale models of the bottom of the new medium endurance Coast Guard cutter. The ends of all members of the model were fixed so that end fixity approached that of the actual ship. [6] Weight of the model carriage was such that the slamming of a ship was accurately simulated in

in the test apparatus. [8] A detailed plan of the model and a bill of materials is given in Plate 1. Pictures of the model are shown in Figures II and III.

It was necessary to provide a longitudinal separation between the halves of the model so that two backing materials could be tested in one model. This was accomplished by installing a thin vertical plate from the keel to the level of the tank top. So that the properties of the model would not be appreciably affected by this partition, it was made as light as possible.

Drain plugs and filling connections were installed to facilitate the loading and unloading of the liquids used in part of the test program. Pipe plugs were installed on each side of the model, and small holes were drilled in the stiffeners near the plating to insure complete drainage. A means of filling the models was provided by building manholes into the top of the model carriage. These arrangements were necessary; because, as will be discussed later, it was convenient to change liquid levels rapidly in the models during testing.

It was decided to weld a heavy flange to the top perimeter of the models so that testing could progress without undue delay. The models could then be bolted to the carriage instead of being welded as in previous tests. This modification greatly reduced the time necessary to install or remove a model from the drop carriage. The problem of watertightness between the model and the carriage was solved

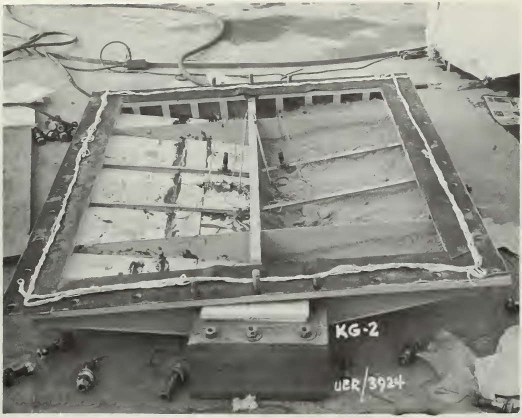


Figure II
Model Ready for Installation on Carriage

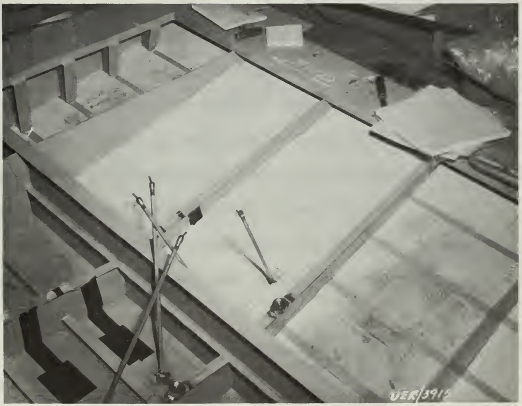


Figure III
Model Showing Deflection Gages, Strain Gages, Velocity Meter Holders and ML-D2 Being Installed

by using a $\frac{1}{4}$ inch neopreme gasket, oakum and taking up on the holding bolts with a compressed air wrench. (See Figure II.)

As several of the proposed backing materials had to be contained, it was necessary to fabricate a tank top for the model. The tank top was a light plate, longitudinally stiffened, large enough to cover the model top. An opening was built into both sides of the tank top to permit loading of the liquid backing.

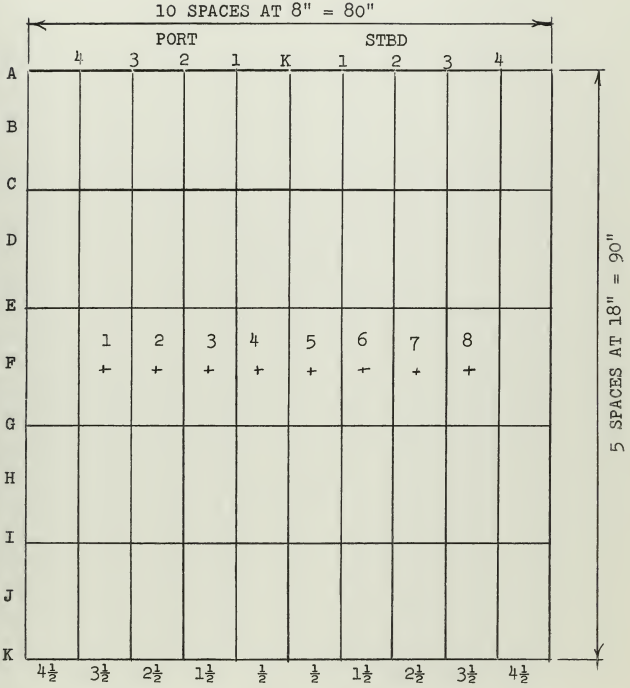
Data was obtained by using piezo-electric pressure gages (PE), SR-4 strain gages (S), velocity meters (VM), accelerometers (AC), and deflection gages (MD). The data was recorded by magnetic tape recorders installed aboard the UEB-1 experimental barge of the Underwater Explosives Research Division (UERD) of the David Taylor Model Basin, located at the Norfolk Naval Shipyard. Instruments were triggered by an explosive bolt and a contact when the keel was 6 inches above the water. Readings were taken over a 40 msec period covering full model immersion of 12 inches. The instruments and recorders were chosen because of excellent results obtained in previous tests. [6]

All data will be presented in graphs, plotted against time. Cross plots are made to give added simplification of details.

The location of the various sensors is shown in Figures IV through VIII. Each sensor is designated by its letter abbreviation and a number. Pressure and deflection gages were located in such a way that deflections calculated from

INSTRUMENTATION

OUTSIDE BOTTOM

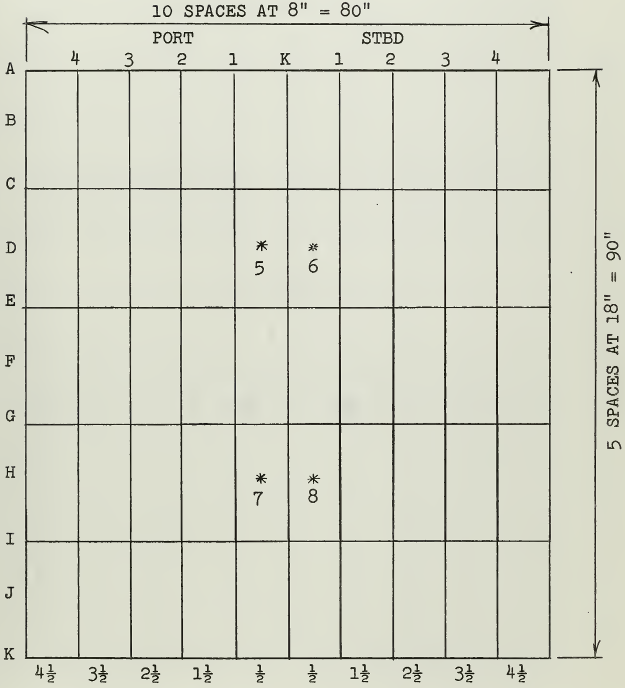


\+ = PE = PRESSURE GAGE

FIGURE IV

INSTRUMENTATION

OUTSIDE TOP

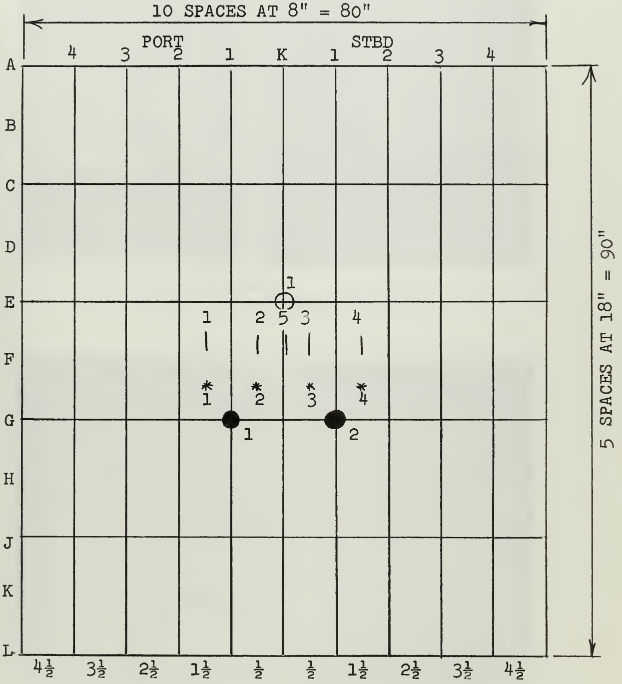


* = MD = DEFLECTION GAGE

FIGURE V

INSTRUMENTATION

INSIDE BOTTOM



= AC = ACCELEROMETER = S = STRAINGAGE

= VM = VELOCITY METER * = MD = DEFLECTION GAGE

FIGURE VI

Figure VII
View of Instrumentation Installed in Model

Figure VIII
View of Pressure Gages Installed on Model Bottom

Nagai's theory [9,10,11] of slamming could be checked with MD gage readings if desired. Velocity meters, accelerometers and strain gages were located so as to conform with their placing in other models tested in this program.

In order to take a complete set of offsets of the model bottom, jigs were mounted on the model flange at the forward and after end as shown in Figure IX. The jig formed a straight edge projection $\frac{1}{2}$ inch below the bottom plating. At each point where a line of offsets were desired, a thin wire was stretched between the jigs with considerable tension. The deflection at all designated points along the wire was measured from the wire to the model bottom with a steel rule graduated in hundredths of an inch. (See Figure IX.) Each reading was designated by means of the coordinates shown in Figure IV and recorded on specially prepared sheets for future reference.

A complete set of deflections was taken at each mid-point on the grid before each model was dropped. When all drops were completed on a given model, another complete set of deflections was taken and the net deflection caused by slamming was computed. The net deflections were used as a check on the values obtained from the deflection gages.

A testing program was devised to evaluate the various backing materials, making use of the test apparatus available at the UERD. Detailed plans of the test rig will be found at the end of this paper. Pictures of the test rig are shown in Figures X and XI.

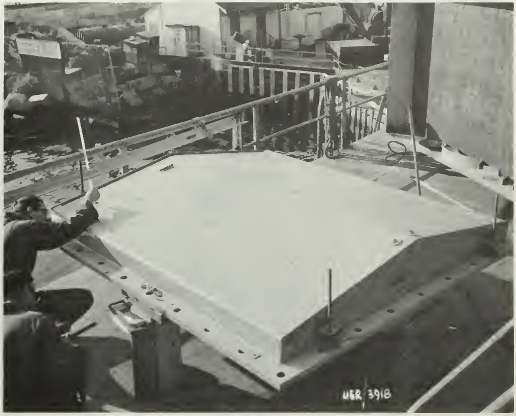


Figure IX
Technicians Taking Offsets on Model Prior to Initial Drop

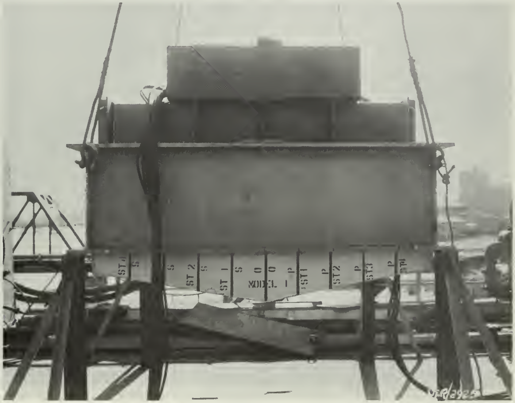


Figure X
Model and Carriage Prior to Installation in Drop Rig

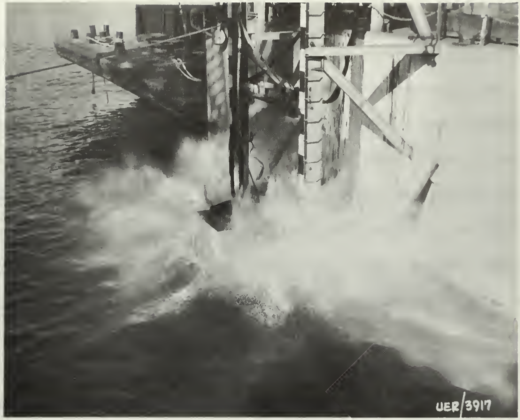


Figure XI
Model Striking Water During a Test

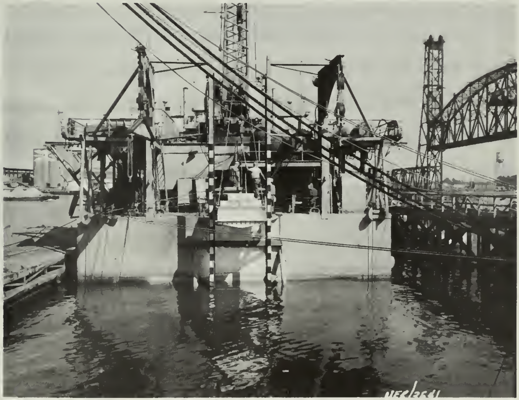


Figure XI-a
Model Mounted in Drop Rig Prior to a Test

Tests were run to find out if an optimum liquid loading level existed. Four liquid levels which "bracketed" the probable optimum were selected. One model was loaded to each of these levels and dropped from four feet. The resulting elastic deflection of the bottom plating and tank tops for each drop were compared, and the level which gave the least deflection was selected as optimum. Each backed model was loaded with this optimum weight of backing material before testing.

Each model was dropped into calm water from four feet once to collect data in the elastic deflection range. They were then dropped three times from a height of ten feet to obtain data in the plastic deformation range and to see if the plastic deformations approached a limiting value with repeated slams of the same amplitude.

In all experiments it is necessary to have a control or standard against which to judge other parts of the experiment. In this instance one model was put through the testing program with no backing material, but was instrumented in the same manner as the backed models. All data obtained in other drops was compared with the data obtained from this model to judge the effectiveness of the various backings.

III. THEORY

A. Liquid backing:

The following theory applies to an unrestrained plate subject to a plane underwater shock wave.

Let us assume that the entire plate travels with a velocity "v(t)." The impinging pressure wave is a function of time and will be designated $p(t)$. For this argument we will assume an exponential wave

$$p(t) = p_o e^{-t/\theta}$$

where p_o is the maximum pressure and θ is the decay time. Upon impact of the wave, a reflected wave is produced. The resulting pressure is $p(t)$ for a rigid plate. However, due to movement of the plate, this pressure is reduced by an amount $\rho''c''v(t)$, where "c" is the speed of sound in water. Therefore the total pressure acting upon the plate is

$$2p(t) - \rho''c''v(t)$$

Defining "m" to be mass per unit area of plating and applying Newton's law

$$m\dot{v}(t) = 2p(t) - \rho''c''v(t)$$

For our exponential wave, the solution is [12]

$$v(t) = \frac{2p_o}{\rho''c''} \; \frac{1}{\frac{m}{\rho''c''\theta} - 1} \quad e^{-t/z\theta} - e^{-t/\theta} \quad ; \; z = m/\rho''c''\theta$$

In a liquid backed plate, the transmitted wave, $p_{tr} = \rho''c''v(t)$ must be considered. Our differential equation becomes in this case

$$m\dot{v}(t) = 2p(t) - 2\rho''c''v(t)$$

The velocity produced in the second case is approximately one half of the first. However, the p_{tr} will travel with a velocity of about twice that of the bottom plating, causing damage to the tank top if there is no free surface present.

While the slamming pressure is not of the exact form

$$p(t) = p_o e^{-t/\theta}$$

it is quite similar and the above theory is valid. [6]

B. Visco-Elastic backing:

A visco-elastic material dissipates energy due to the disruption of the molecular bonds of its long chain molecules. [13,14,15] This is further explained by the fact that, for an oscillating stress, the resulting strain will be out of phase with the stress. This is accounted for in analysis by assuming a complex modulus $E_2^* = E_2 \ (1 + j \ \eta_2)$, where η_2 is the loss factor of the visco-elastic material. The greater the phase lag, the greater will be the energy absorption.

While the damping properties of these materials are slowly varying functions of the ambient temperature and frequency of the alternating stress, they are independent of the amplitude of vibration except at very high strains. [13,14,16] Due to the availability of many types of damping materials, it is not usually too difficult to obtain a visco-elastic material with acceptable properties within any reasonable range of temperature and frequency. This temperature and frequency dependence of the Young's modulus and loss

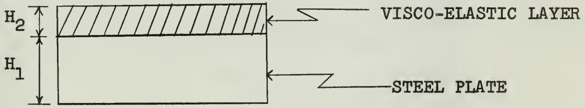
factor of a typical damping material, polyvinylchloride, is shown in Figure XII.

Only damping resulting from extensional deformation of the visco-elastic layer will be considered in this paper. This is the mechanism that occurs when a single layer of damping material is applied to a plate. The earliest theoretical analysis was conducted by Oberst and associates [17-19] in Germany and Lienard [20] in France. They determined that the damping depends upon the loss factor of the damping material, its stiffness and the thickness of the layer applied. The following equations are based upon "thin plate" theory where all thicknesses are assumed small with respect to the wave length of the motion of the plate.

$$\eta = \frac{\eta_2 e_2 h_2 (3+6h_2+4h_2^2)}{1+e_2 h_2 (3+6h_2+4h_2^2)} \quad (1)$$

(See Figures XIII and XIV.)

where $e_2 = E_2/E_1$ and $h_2 = H_2/H_1$



Ross et al [13] have further simplified this expression for the case of a steel plate having $E_1 = 2.0 \times 10^{12}$ dynes/cm^2 and damping material having $\eta_2 E_2 = 10^{10}$ dynes/cm^2. This represents a maximum loss factor of the form

[illegible]

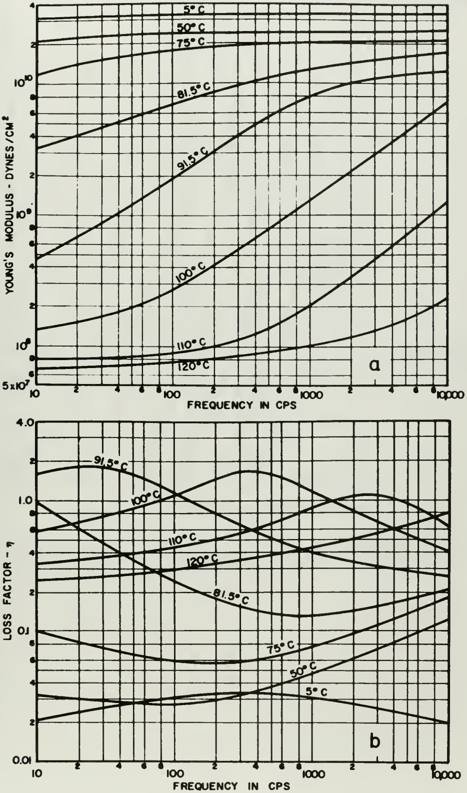
[illegible]

[illegible]

[illegible]

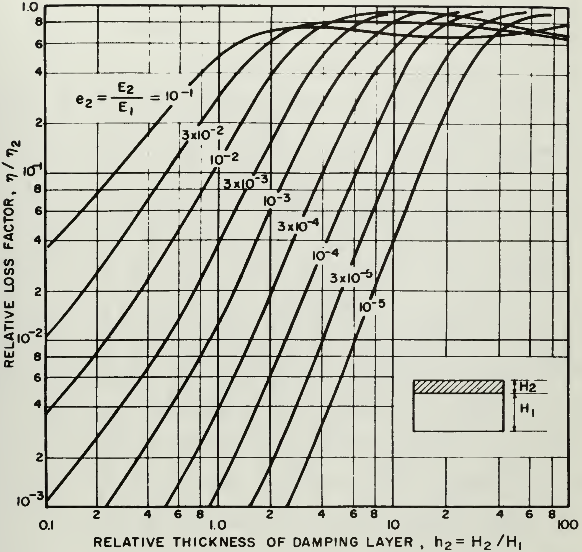
[illegible]

Figure XII

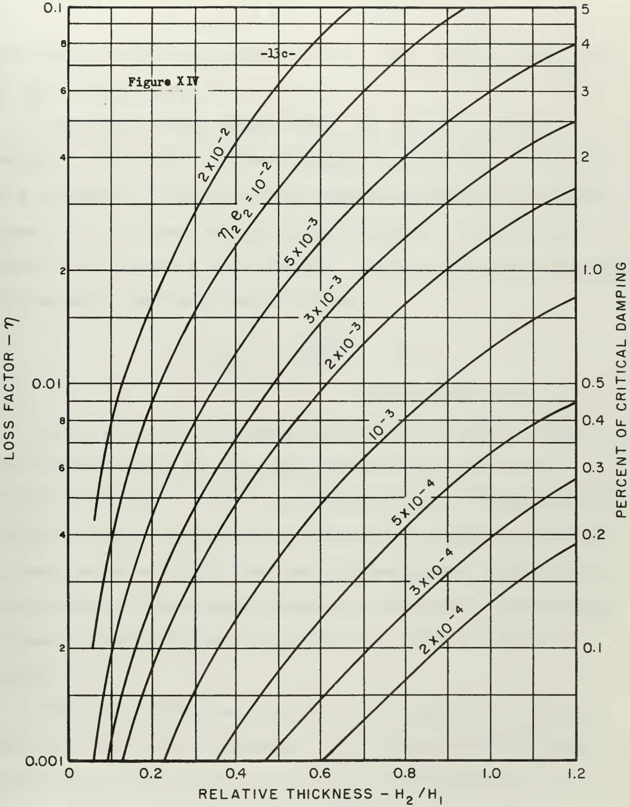


Frequency and Temperature Dependence of (a) Young's Modulus and (b) Loss Factor of Polyvinylchloride

Figure XIII



Relative Damping as a Function of Relative Thickness and Relative Young's Modulus of Homogeneous Damping Layer (After Oberst .



DAMPING OF HOMOGENEOUS TREATMENTS FOR MODERATE THICKNESSES.

$$\eta_{steel} \leq 0.065\ (H_2/H_1)^2 \qquad (2)$$

for damping layer thicknesses of the same order of magnitude as that of the plate.

In addition they showed that, for a given relative weight of treatment, maximum damping occurs when $\eta_2\ E_2/\rho_2^2$ is a maximum. It follows that lighter damping materials are superior for a given weight of application. If a specific gravity of 0.6 and a loss modulus $\eta_2\ E_2$ of $4x10^9$ dynes/cm^2 are assumed, the loss factor becomes

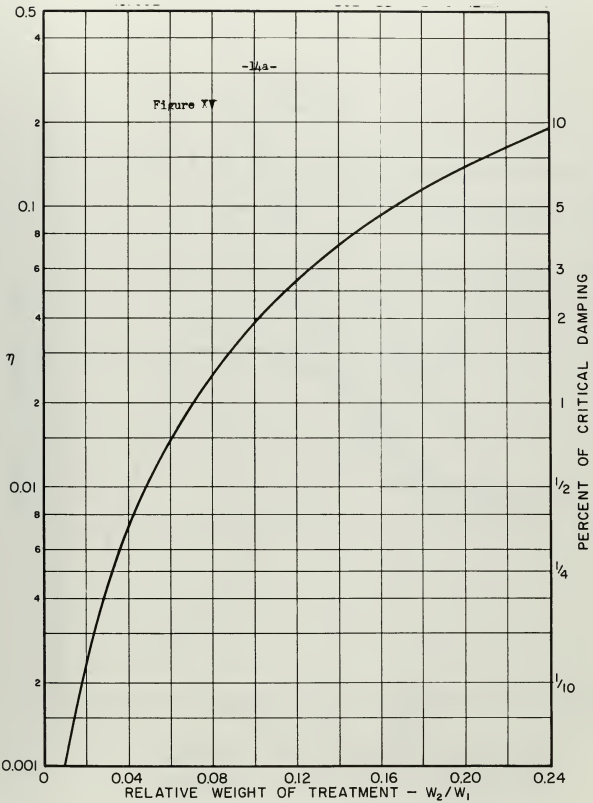
$$\eta_{steel} \leq 4(\frac{w_2}{w_1})^2 \qquad (3)$$

(See Figure XV.)

The visco-elastic damping material to be used in this work was developed by the Naval Material Laboratory in Brooklyn, New York. It is a polyamide-epoxy, aluminum oxide filled material weighing 4.5 pounds per 1'x1'x½" section and is designated as ML-D2. As has been mentioned, properties of visco-elastic material are frequency dependent. ML-D2 shows optimum characteristics ($c/c_c>5$) in the 2000 to 8000 cps range [21].

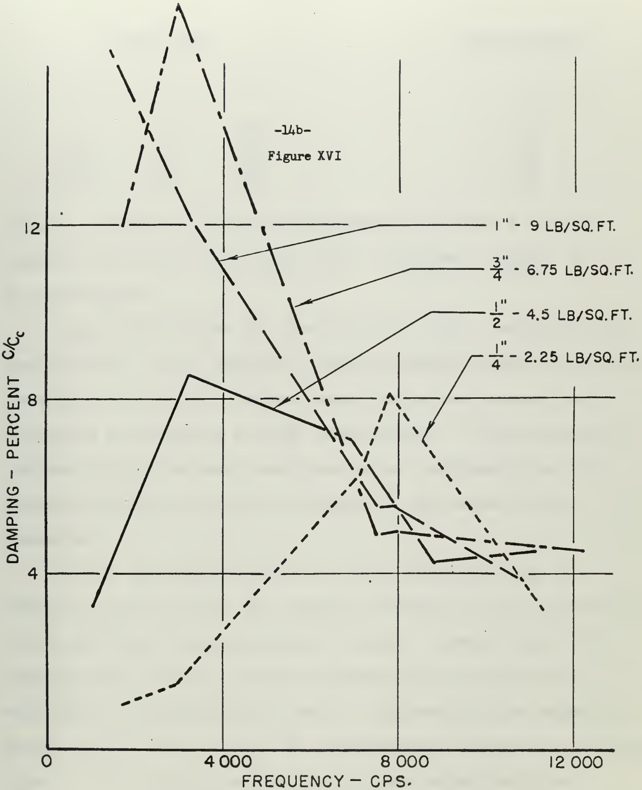
Figure XVI shows an increase in the damping ability of ML-D2 with increased thickness. This increase occurs over all frequencies below 6000 cps but is more pronounced at the lower frequencies. Kallas and Rufolo [21] have shown that at 4000 cps the square law relationship of equation (2) is satisfied quite well.

Figure XV



DAMPING AS A FUNCTION OF RELATIVE WEIGHT FOR BEST KNOWN DAMPING MATERIALS.

Figure XVI



DAMPING PERFORMANCE OF ML-D2
SHOWING EFFECT OF THICKNESS

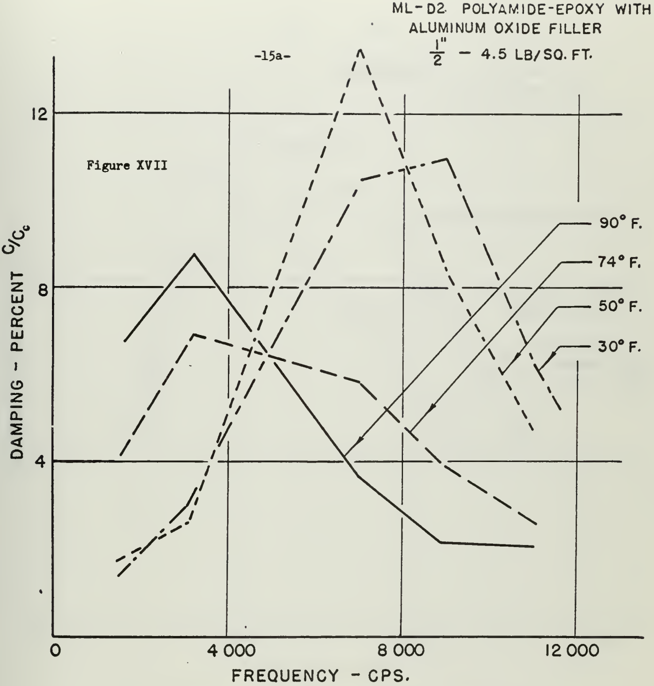
EXPERIMENT			CALCULATIONS
H_2/H_1	C/C_c	η	η
.66	2.5	.05	.03
1.33	9	.18	.11
2.00	11	.22	.25
2.66	14	.28	.46

However, equation (2) does not appear to be valid at frequencies above and below 4000 cps. A maximum H_2/H_1 of 2 is recommended.

Figure XVII shows the variation of C/C_c of ML-D2 with temperature. It is apparent that the material has better high frequency performance at low temperatures and better low frequency performance at high temperatures. This indicates improved high frequency performance and decreased low frequency performance as the stiffness of the material is increased.

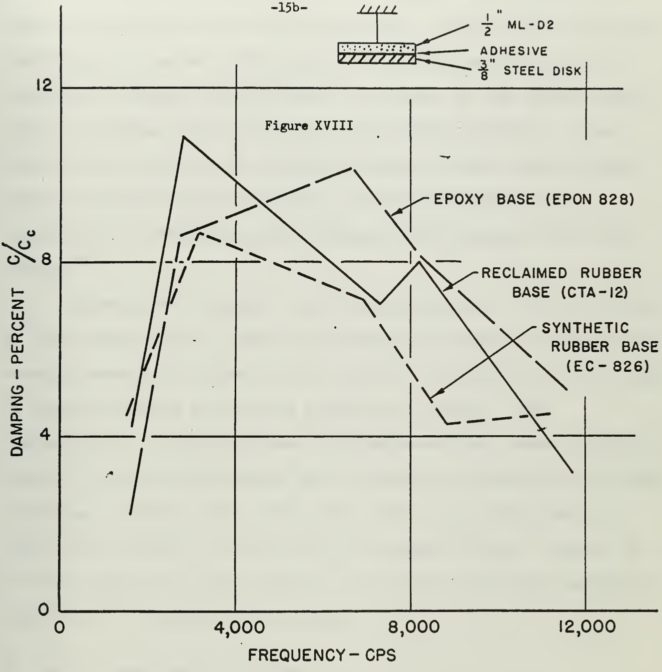
Kallas and Rufolo [21] have shown that the type of adhesive used to apply the damping material is not critical if it is stiff and non-dissapative itself. Several types of adhesive were tested, and the differences in results are attributed to experimental error. The results are shown in Figure XVIII. The aspects of procurement, storage and application are the controlling factors in the selection of an adhesive.

While the theory of visco-elastic energy absorption is well understood, the development of optimum damping materials continues. ML-D2 was chosen for our work for several reasons. It is readily available from government sources,



DAMPING PERFORMANCE OF ML-D2
SHOWING EFFECT OF TEMPERATURE

Figure XVIII



DAMPING PERFORMANCE OF ML-D2
SHOWING EFFECT OF ADHESIVE

inexpensive*; easy to install and has been proven in shipboard use. One-layer thicknesses have been used satisfactorily in sonar domes and on shell plating in the bow area of U. S. Navy destroyers. The main function of this application is to reduce the ambient noise level in the area of the sonar equipment by damping out vibrations in the shell plating. Since there are no records of slamming damage to these ships either with or without ML-D2 installed, no information on its usefulness in preventing this damage can be gained from this source**.

Although most sources are in agreement that an application of approximately two times the plating thickness is optimum for energy absorption, other factors must be considered in the case of impact loading on the bow plating of a ship. The installation of ML-D2 between stiffeners affords some physical support to these stiffeners and reduces the possibility of their tripping. Further, the added mass near the plating must be taken into account. This will be discussed below. Hence, it is not correct to assume that a two plating thickness application will be optimum in our case.

C. Added mass considerations:

Nagai [9,10,11] has recently developed theories to predict deflections of ships plating subject to slamming loads of various itensity. The authors [7] compared the experimental

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*The cost of 1'x1'x½" section is approximately $1.00.

**Destroyers do not normally experience slamming damage due to their narrow frame spacing and relatively large scantlings.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

results of Clevenger and Melberg [6] with this theory and found the differences to be from 1.8-50°/o of the experimental results. Although the amount of data available was limited and the test model differed from the mathematical model used to formulate the theory, one can nevertheless state that there is order of magnitude agreement.

Nagaii's theory states that deflection is reduced by increasing the weight of the plating. We believe that the added weight of backing material has the same effect.

IV. RESULTS

Testing was carried out in the manner described in Table I. The resulting data is presented in graphical form as recorded by the instrumentation. Figures XIX to XXV present the data for model D-3, while figures XXVI to XXIX and figures XXX to XXXIV present the data for models KG-1 and KG-2 respectively. Due to the amount of data taken, only the data necessary to explain the basic results and conclusions is reproduced in this work. The original copies of all data are on file at the David Taylor Model Basin and will be included in a future DTMB Report.

Table I.

Drop Number	Model Number	Height	Loading Port	Loading Starboard	Figure
5812	D-3	4'	Water	Oil	XIX
5813	D-3	4'	Water	Oil	XX
5814	D-3	4'	Water	Oil	XXI
5815	D-3	4'	Water	Oil	XXII
5816	D-3	10'	Water	Oil	XXIII
5817	D-3	10'	Water	Oil	XXIV
5818	D-3	10'	Water	Oil	XXV
5819	KG-1	4'	Unbacked		XXVI
5820	KG-1	10'	Unbacked		XXVII
5821	KG-1	10'	Unbacked		XXVIII
5822	KG-1	10'	Unbacked		XXIX
5823	KG-2	4'	Sand	ML-D2	XXX

[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

5824	KG-2	10'	Sand	ML-D2	XXXI
5825	KG-2	10'	Sand	ML-D2	XXXII
5826	KG-2	10'	Sand	ML-D2	XXXIII
5899	KG-2	25'	Sand	ML-D2	XXXIV

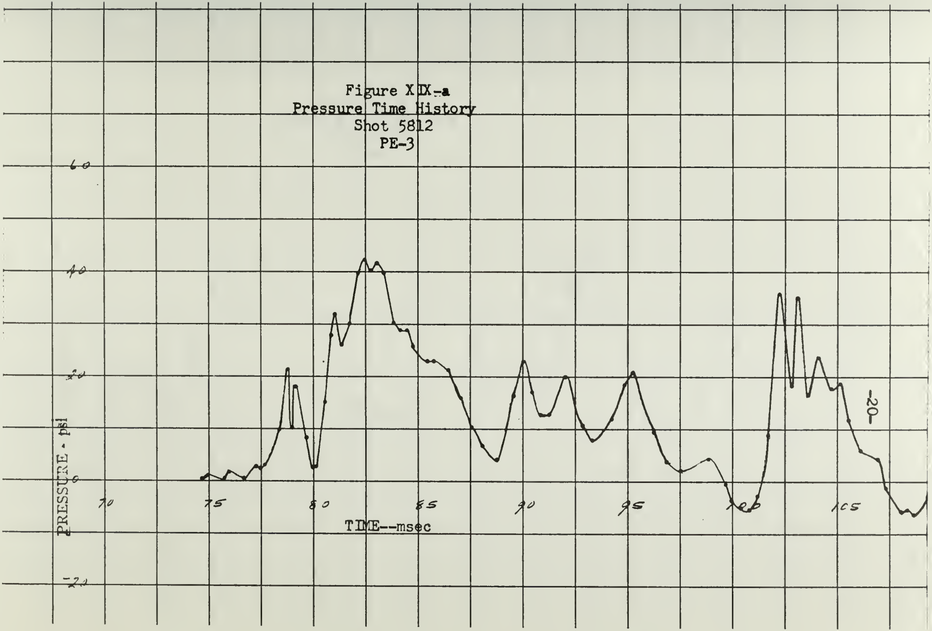


Figure XIX-a
Pressure Time History
Shot 5812
PE-3

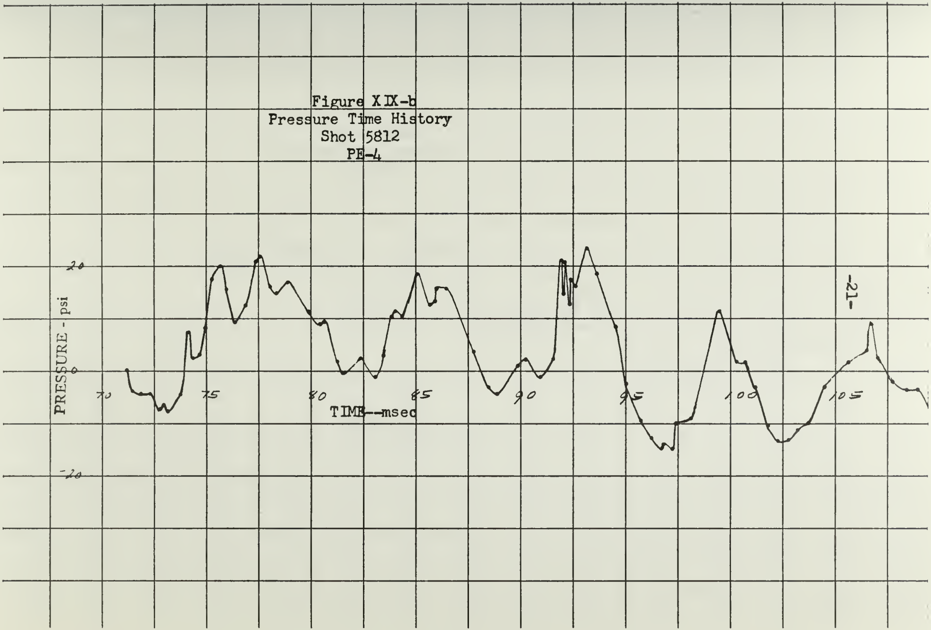
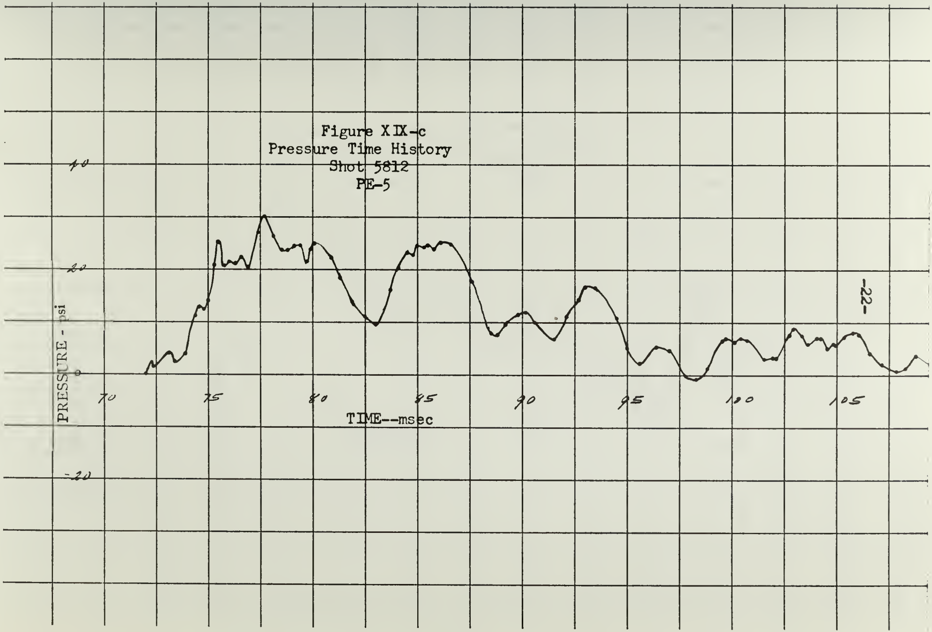


Figure XIX-b
Pressure Time History
Shot 5812
PE-4

Figure XIX-c
Pressure Time History
Shot 5812
PE-5



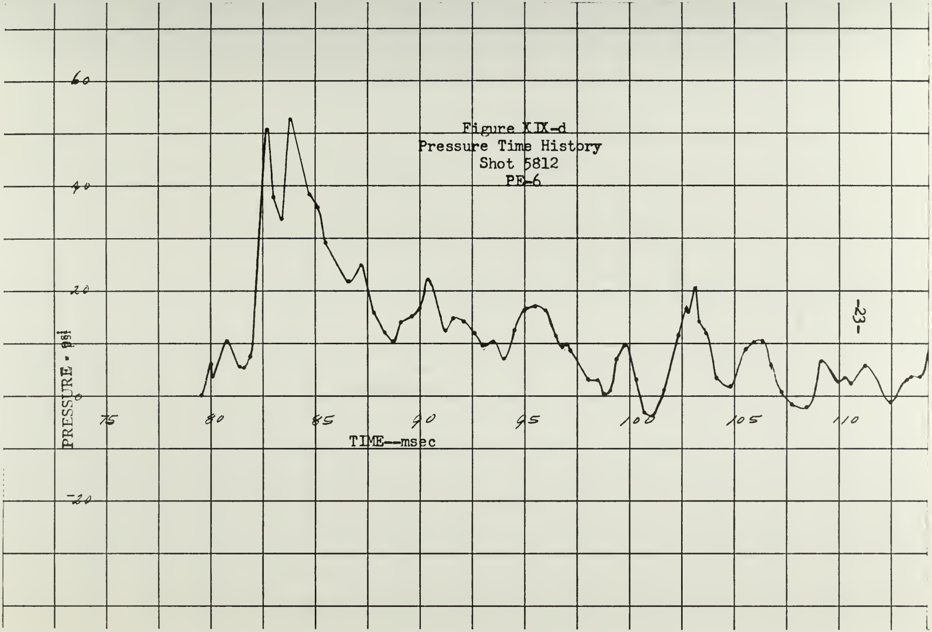


Figure XIX-d
Pressure Time History
Shot 5812
PE-6

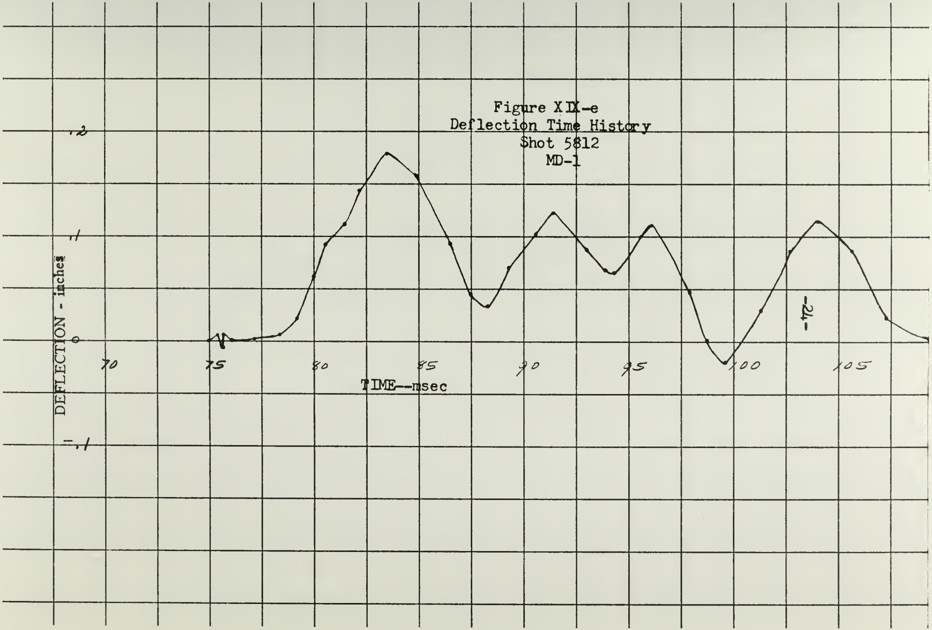


Figure XIX-e
Deflection Time History
Shot 5812
MD-1

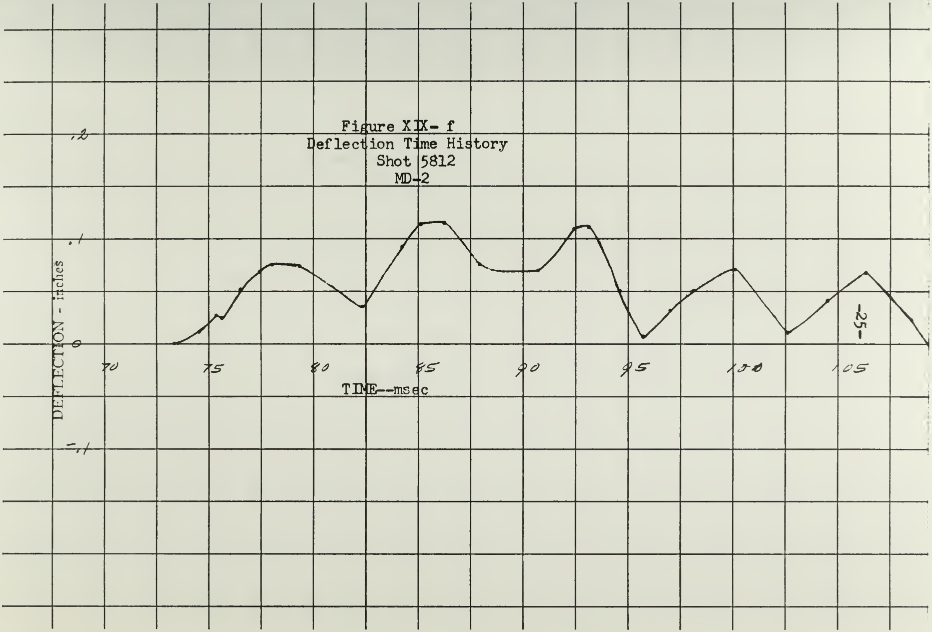


Figure XIX- f
Deflection Time History
Shot 5812
MD-2

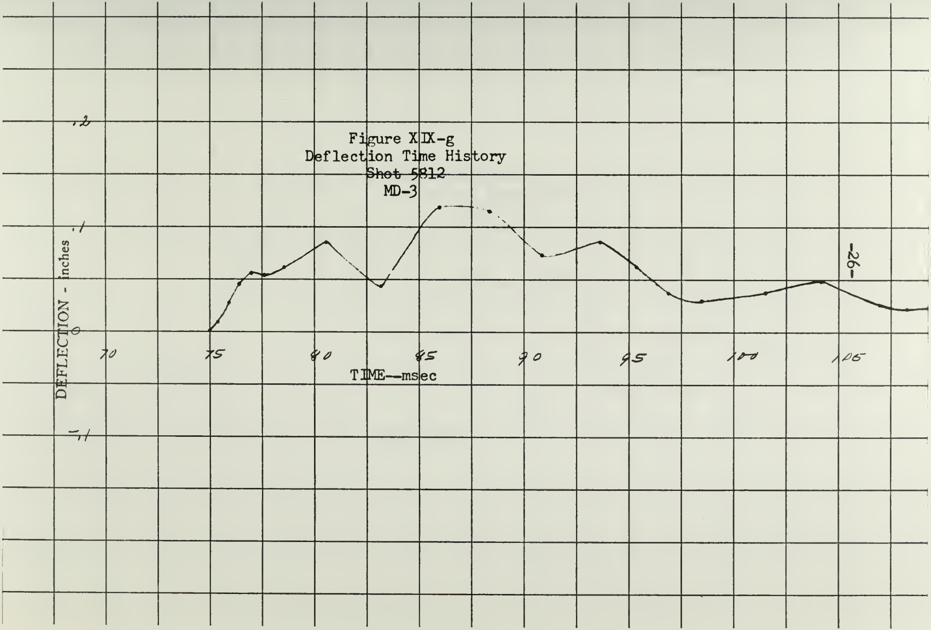


Figure XIX-g
Deflection Time History
Shot 5812
MD-3
DEFLECTION - inches
.2
.1
0
-.1
70
75
80
85
90
95
100
105
TIME--msec

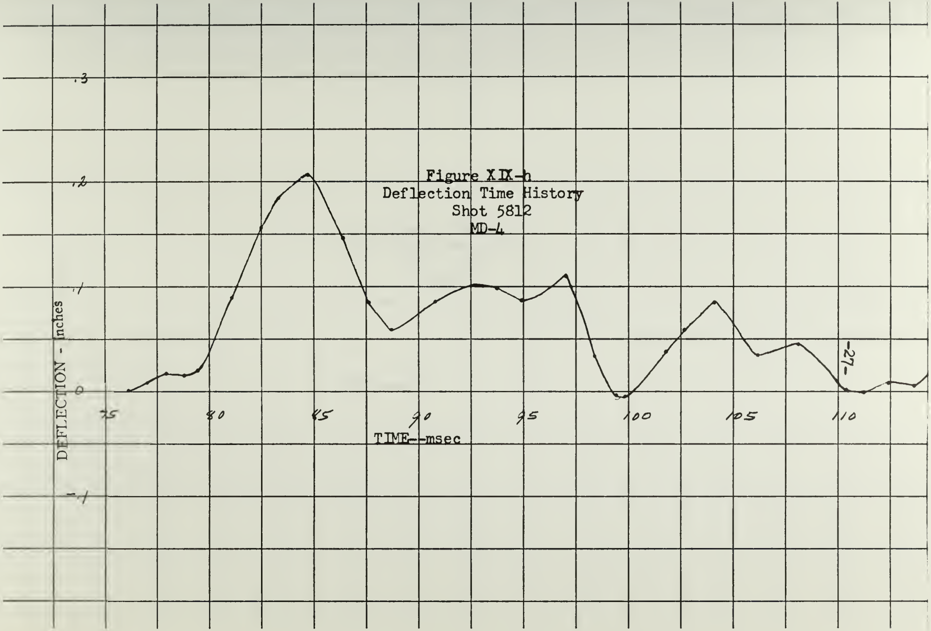


Figure XIX-h
Deflection Time History
Shot 5812
MD-4

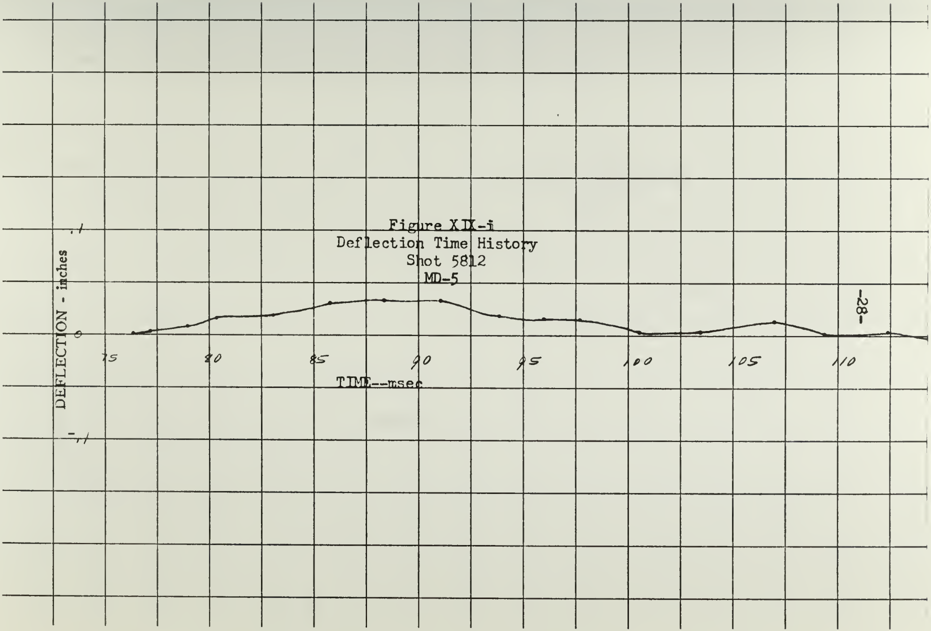


Figure XIX-i
Deflection Time History
Shot 5812
MD-5

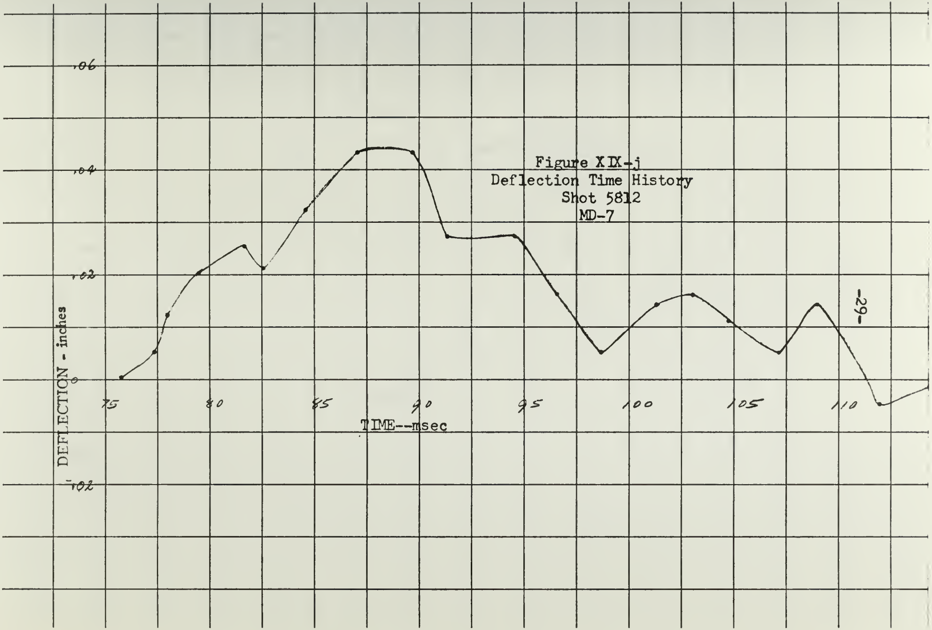


Figure XIX-j
Deflection Time History
Shot 5812
MD-7

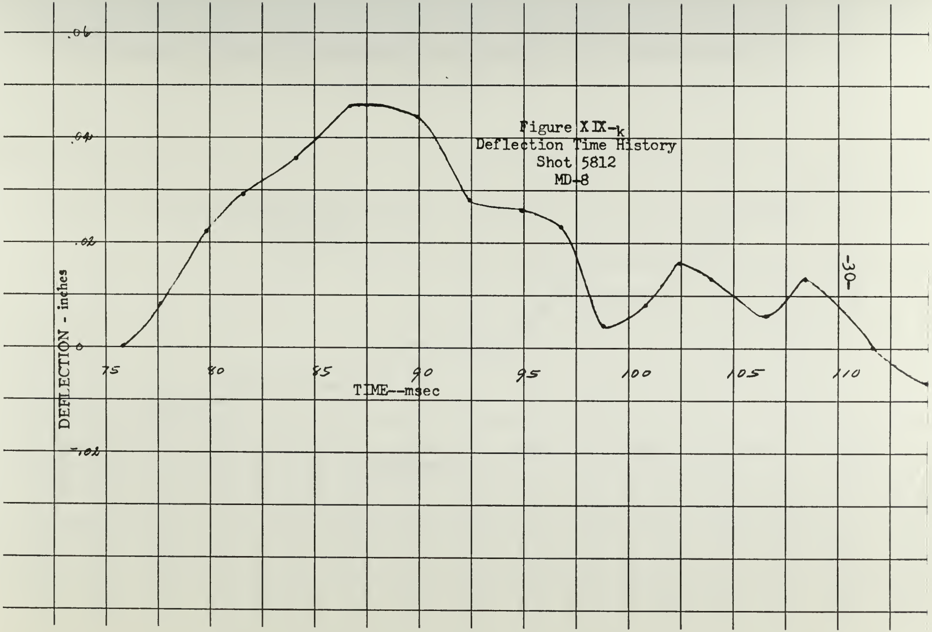


Figure XIX-k
Deflection Time History
Shot 5812
MD-8
DEFLECTION - inches
TIME--msec
.06
.04
.02
0
-.02
75
80
85
90
95
100
105
110

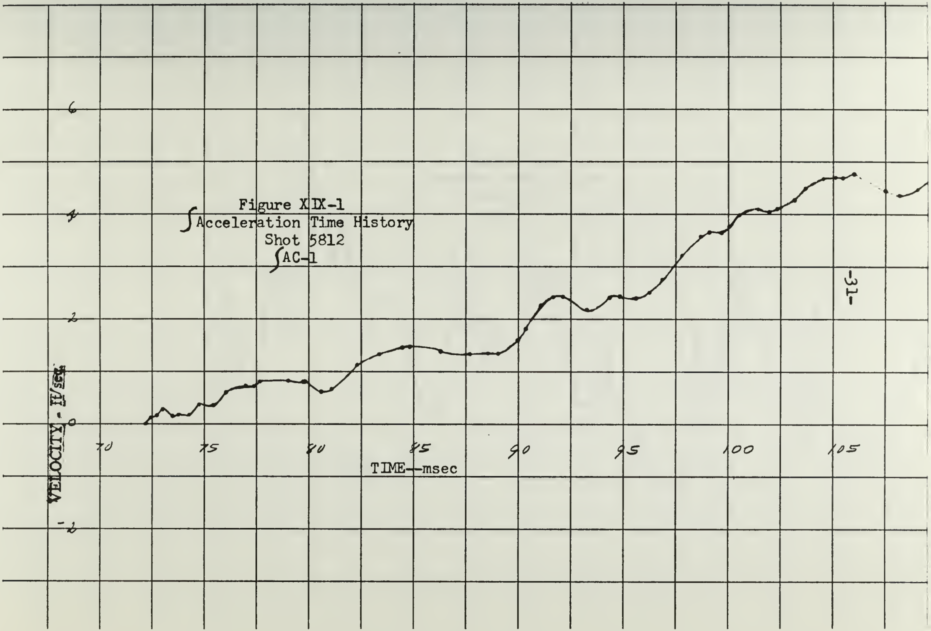


Figure XIX-1
∫Acceleration Time History
Shot 5812
∫AC-1

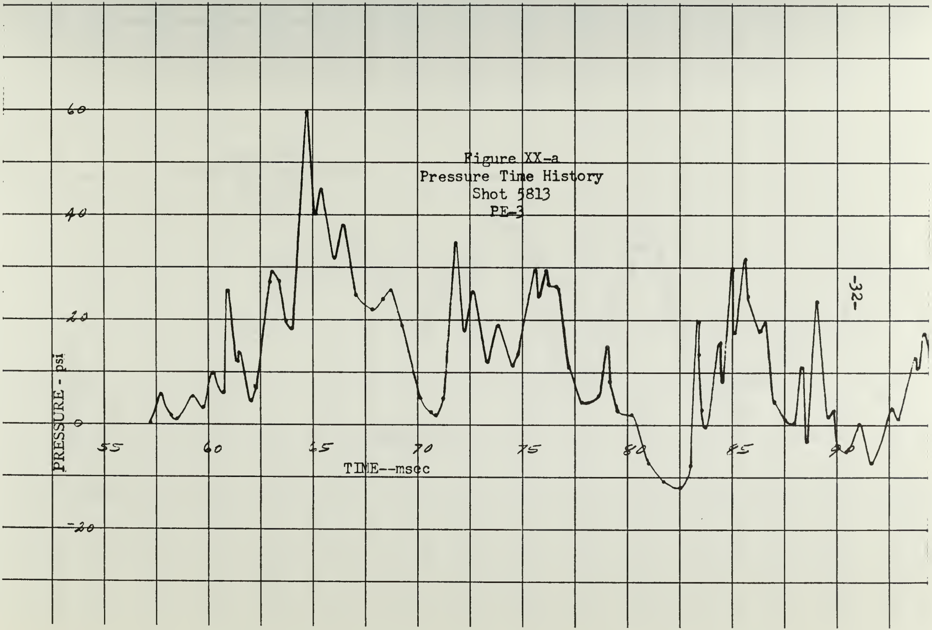


Figure XX-a
Pressure Time History
Shot 5813
PE-3

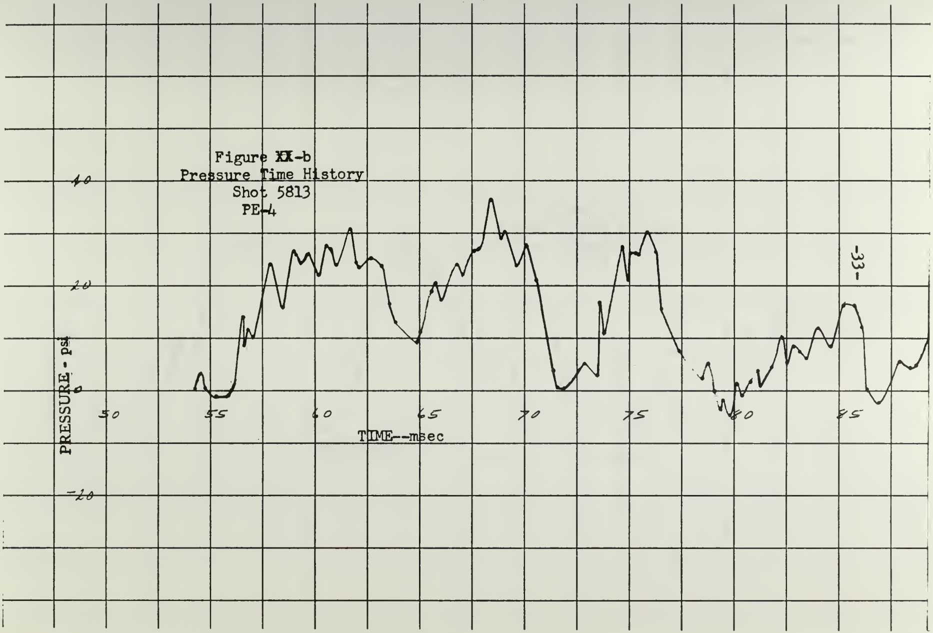


Figure XX-b
Pressure Time History
Shot 5813
PE-4

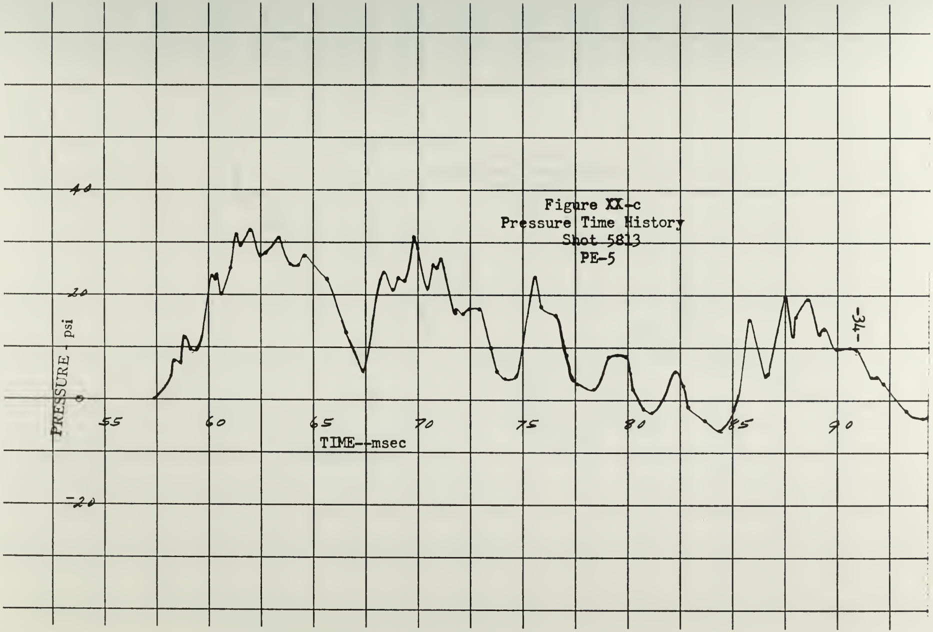


Figure XX-c
Pressure Time History
Shot 5813
PE-5

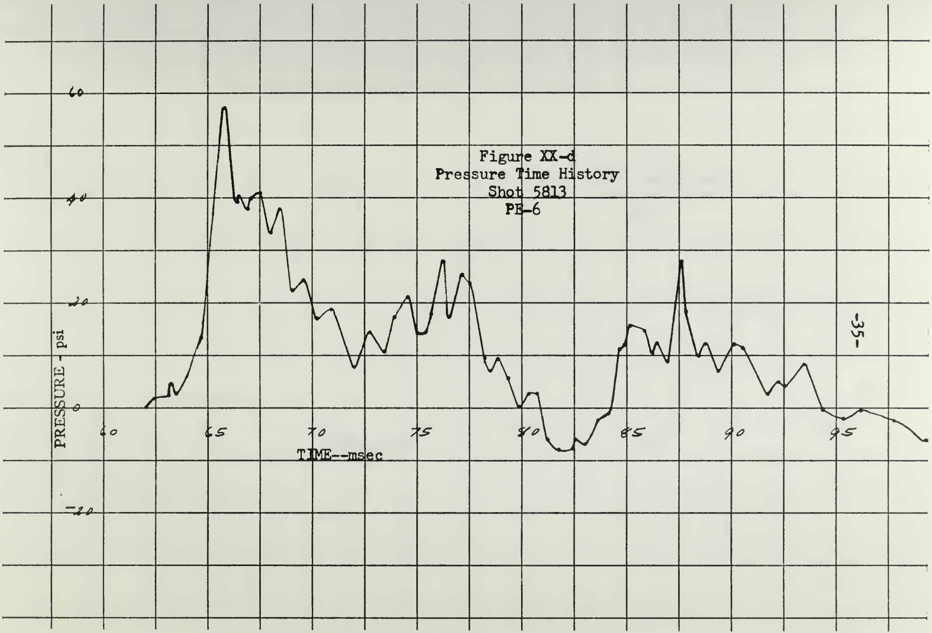


Figure XX-d
Pressure Time History
Shot 5813
PE-6

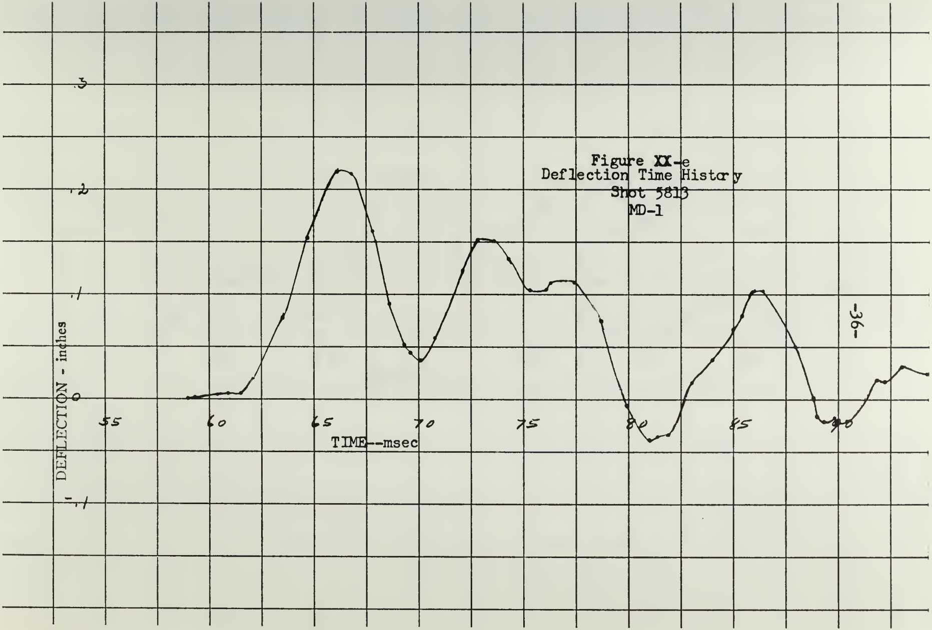


Figure XX-e
Deflection Time History
Shot 5813
MD-1

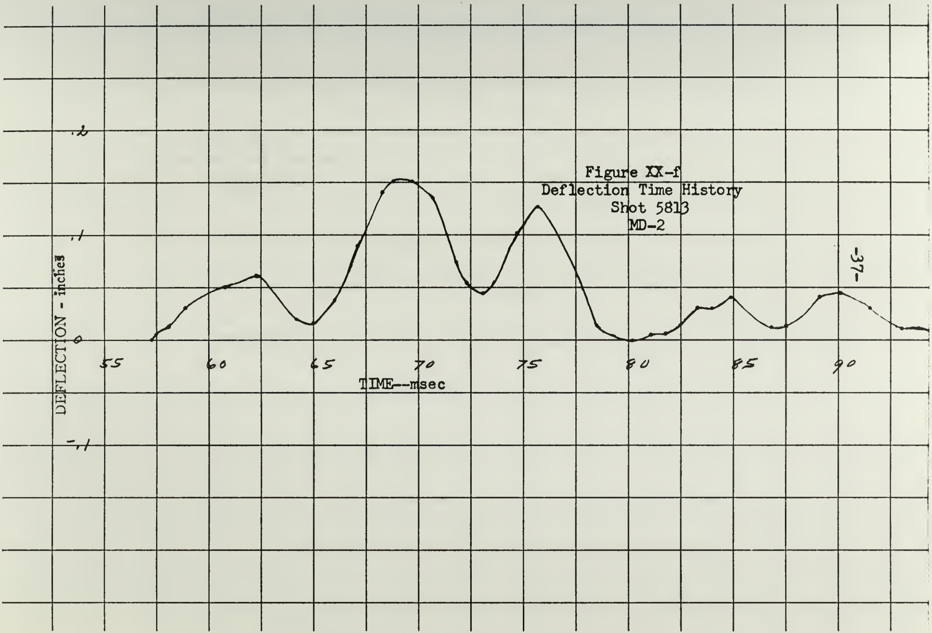


Figure XX-f
Deflection Time History
Shot 5813
MD-2

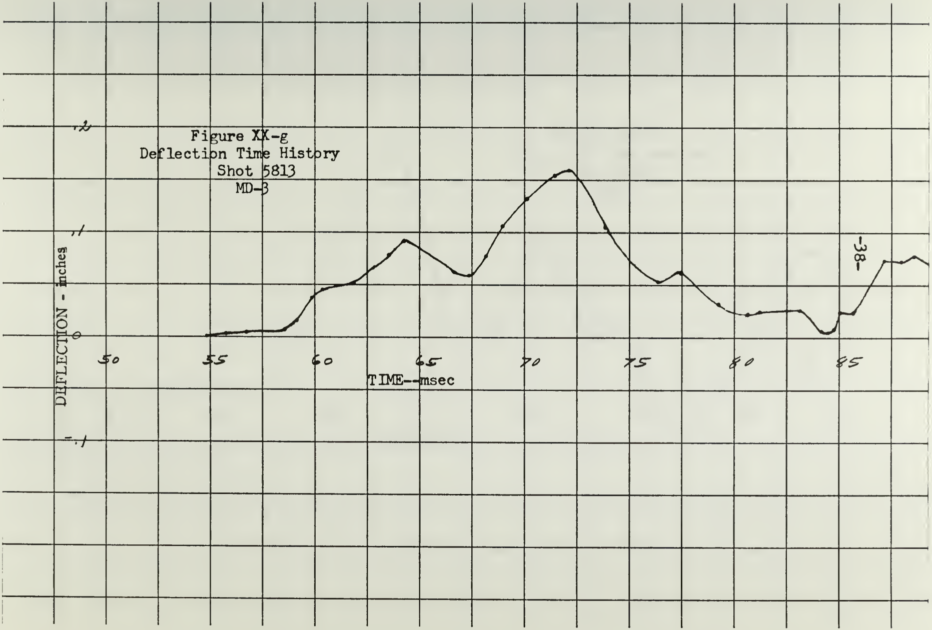


Figure XX-g
Deflection Time History
Shot 5813
MD-3

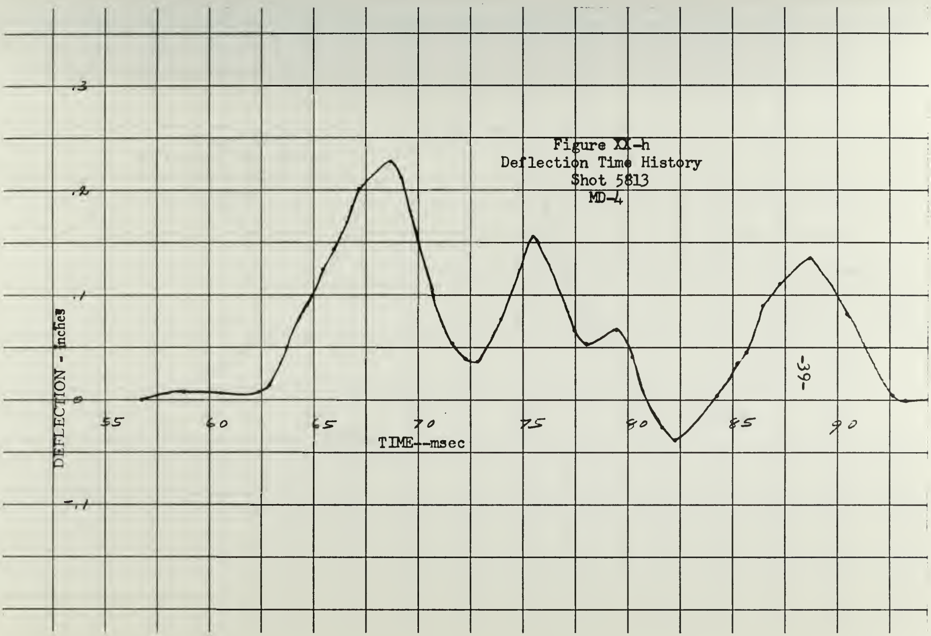


Figure XI-h
Deflection Time History
Shot 5813
MD-4

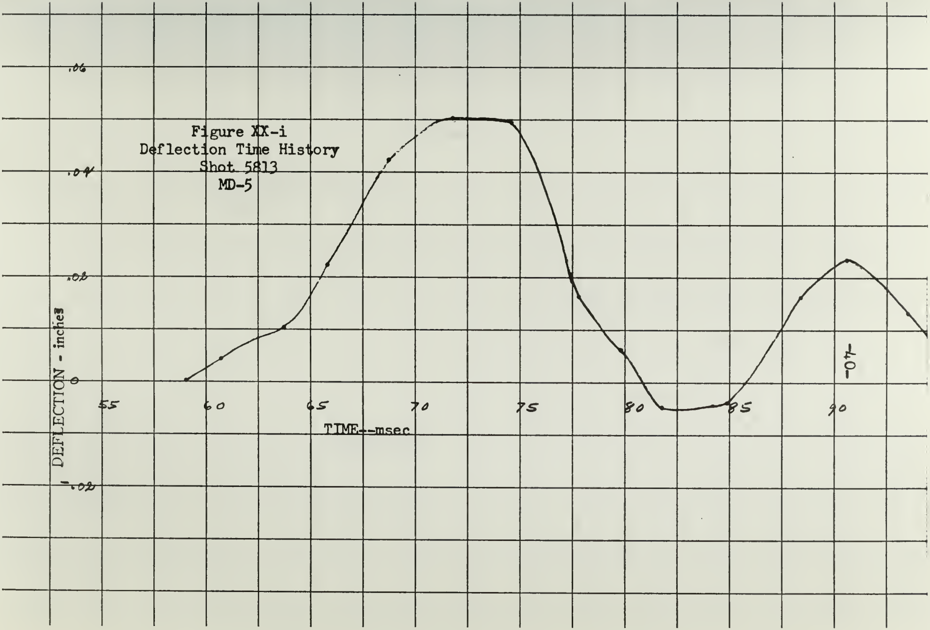


Figure XX-i
Deflection Time History
Shot 5813
MD-5

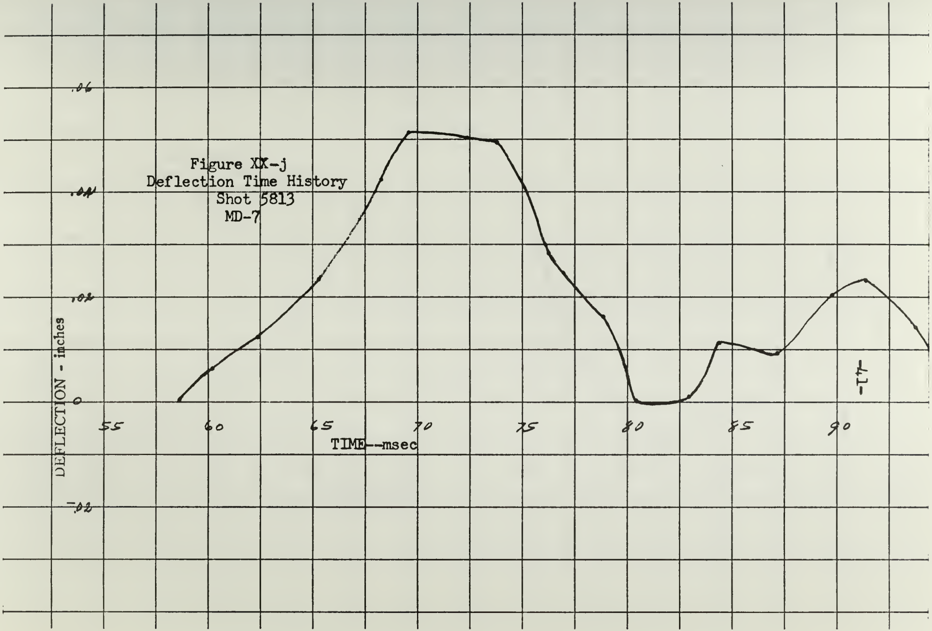


Figure XX-j
Deflection Time History
Shot 5813
MD-7

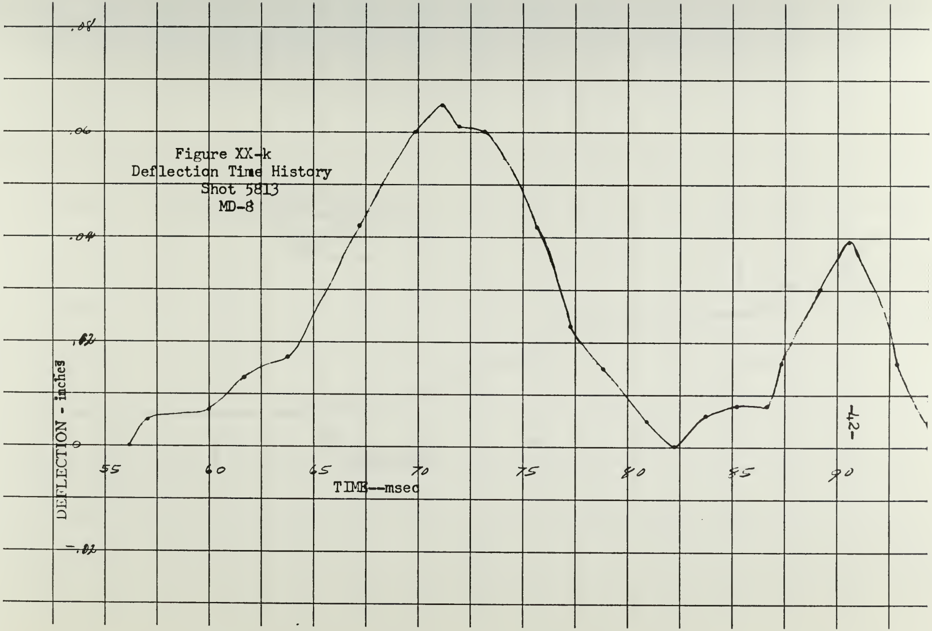


Figure XX-k
Deflection Time History
Shot 5813
MD-8

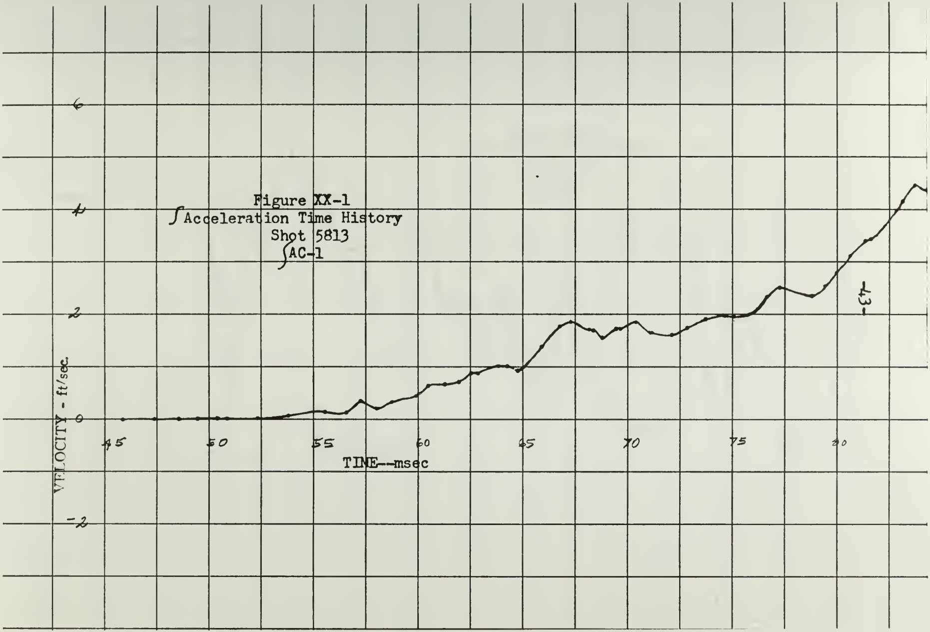


Figure XX-1
∫Acceleration Time History
Shot 5813
∫AC-1

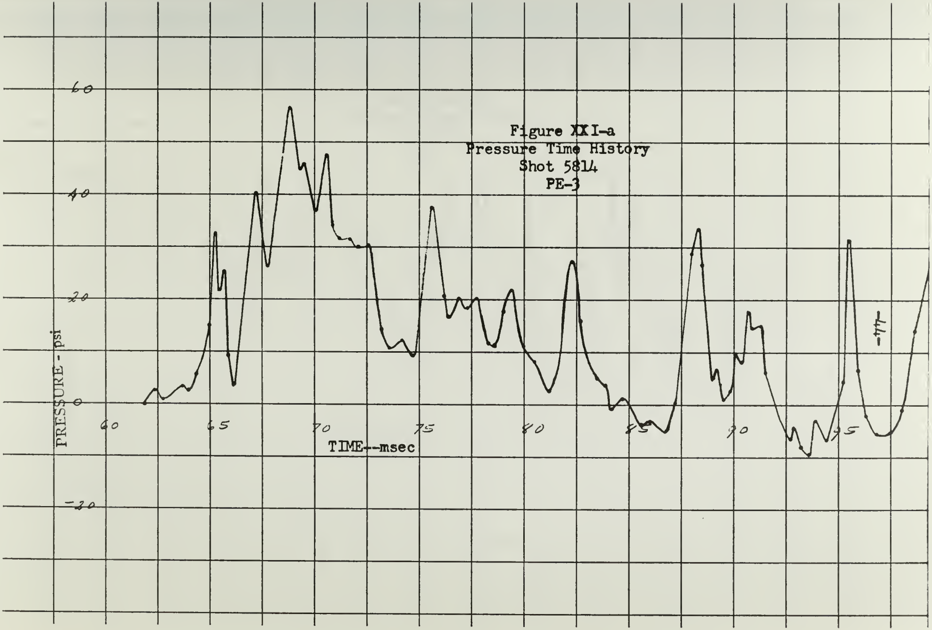


Figure XXI-a
Pressure Time History
Shot 5814
PE-3

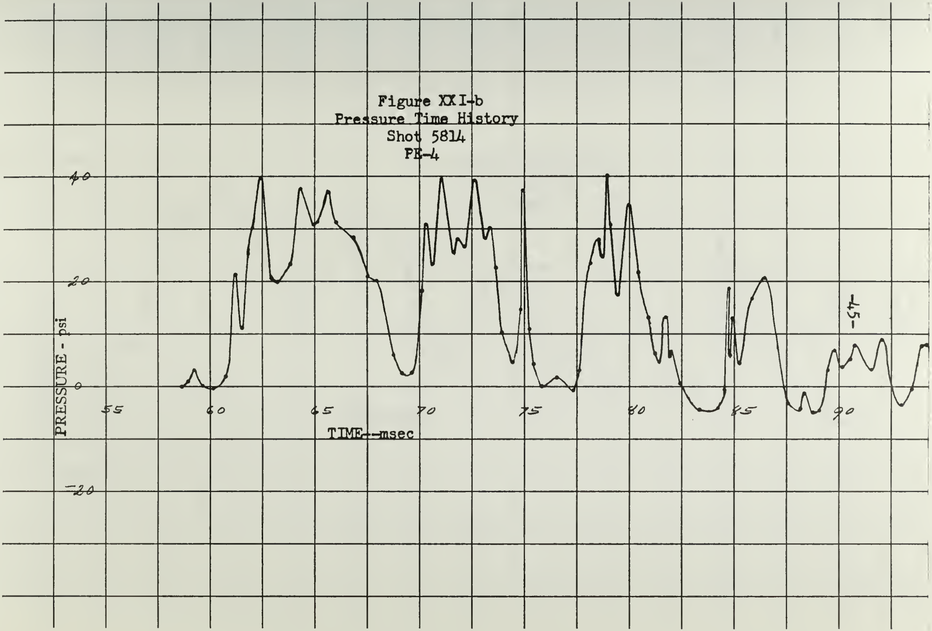


Figure XXI-b
Pressure Time History
Shot 5814
PE-4

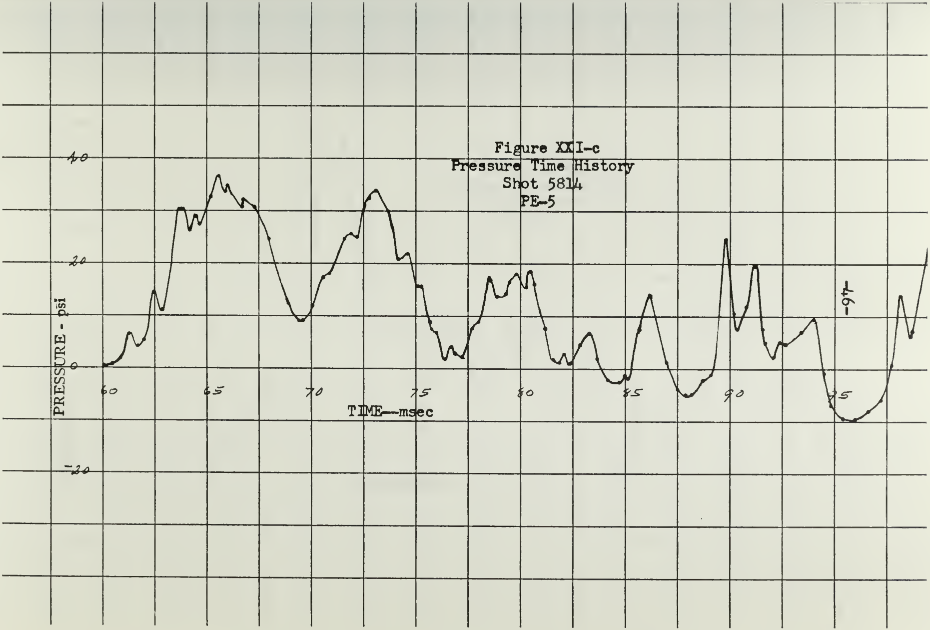


Figure XXI-c
Pressure Time History
Shot 5814
PE-5

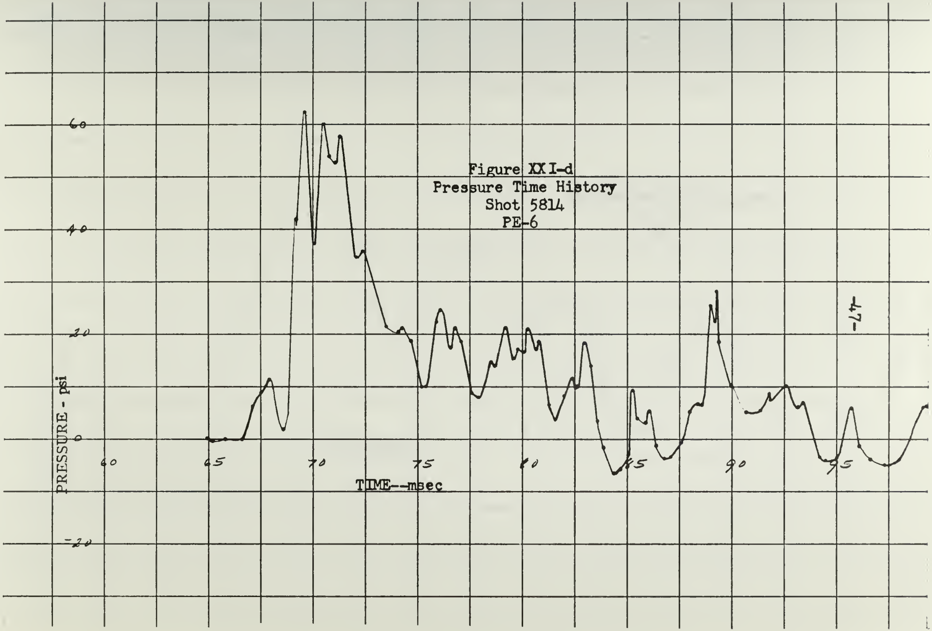


Figure XX I-d
Pressure Time History
Shot 5814
PE-6

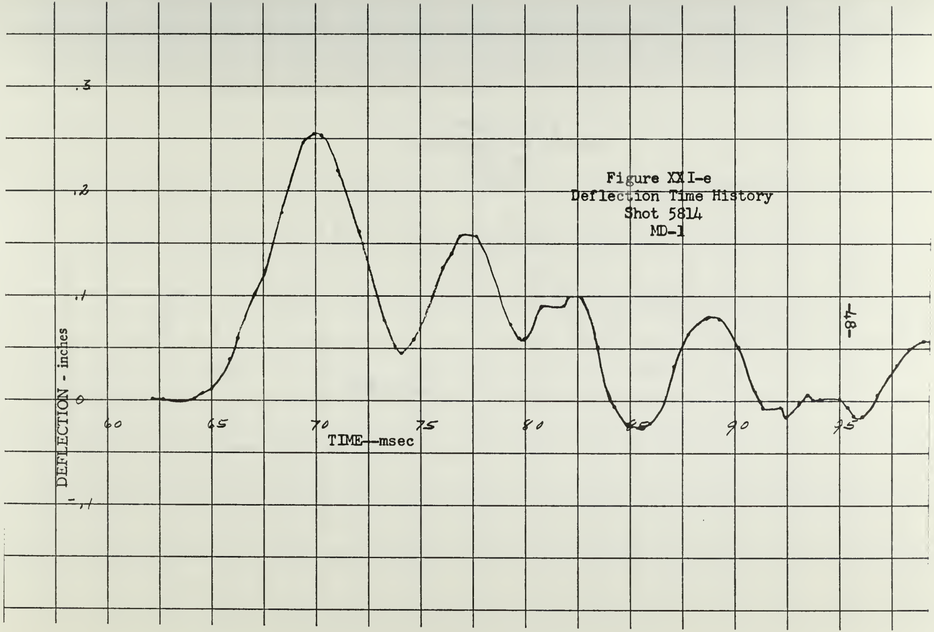


Figure XXI-e
Deflection Time History
Shot 5814
MD-1

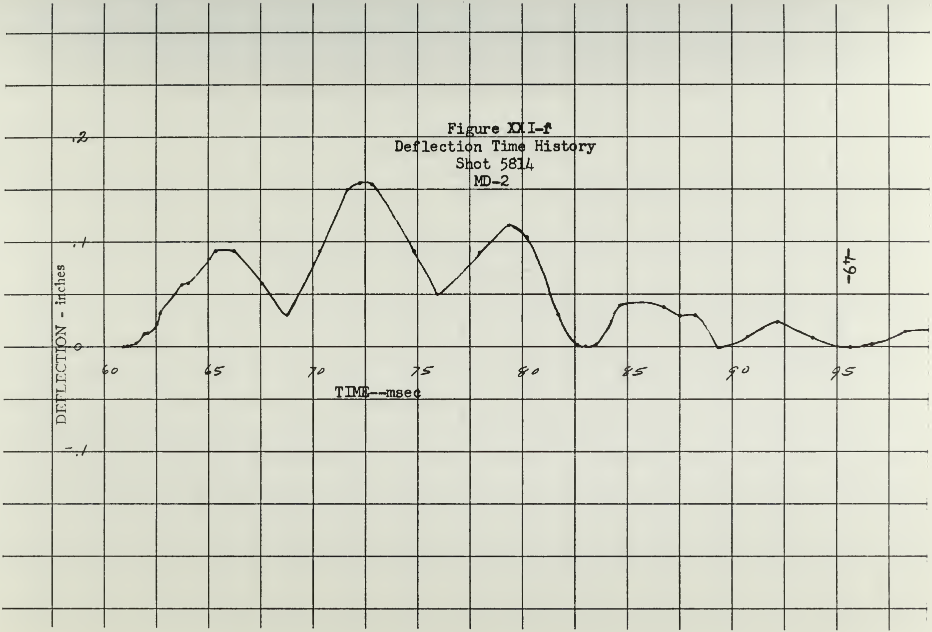


Figure XXI-f
Deflection Time History
Shot 5814
MD-2

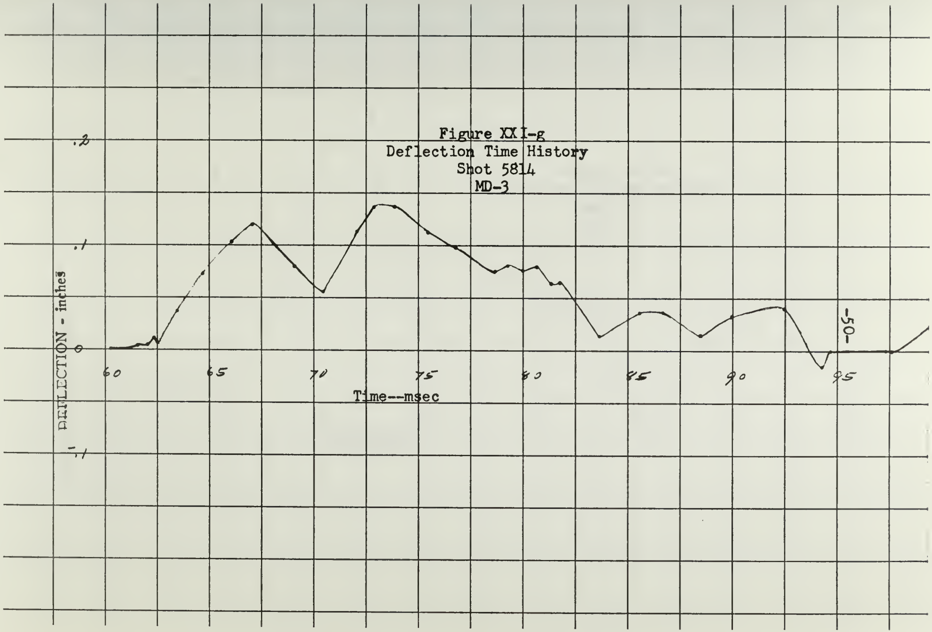


Figure XXI-g
Deflection Time History
Shot 5814
MD-3

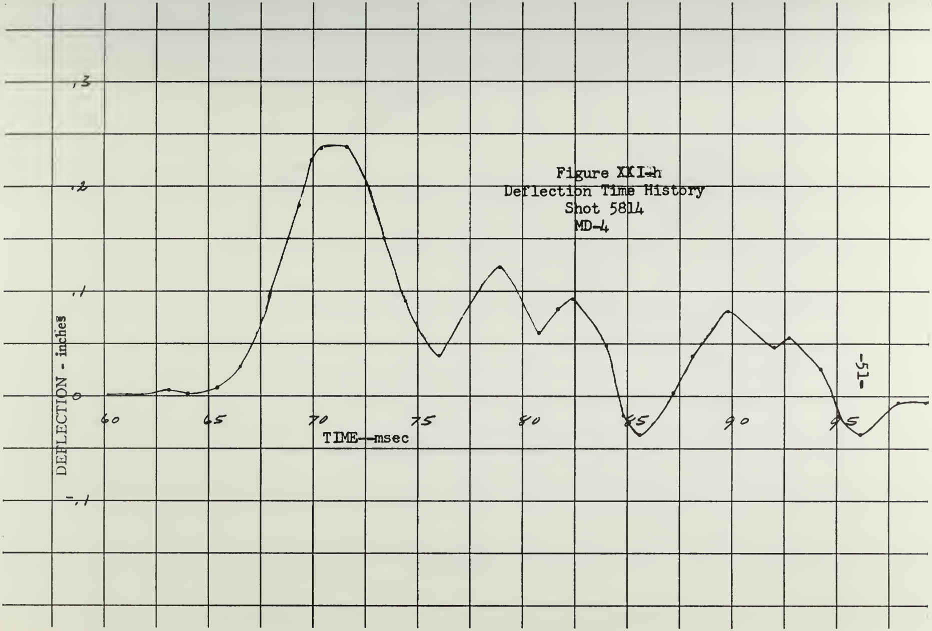


Figure XXI-h
Deflection Time History
Shot 5814
MD-4

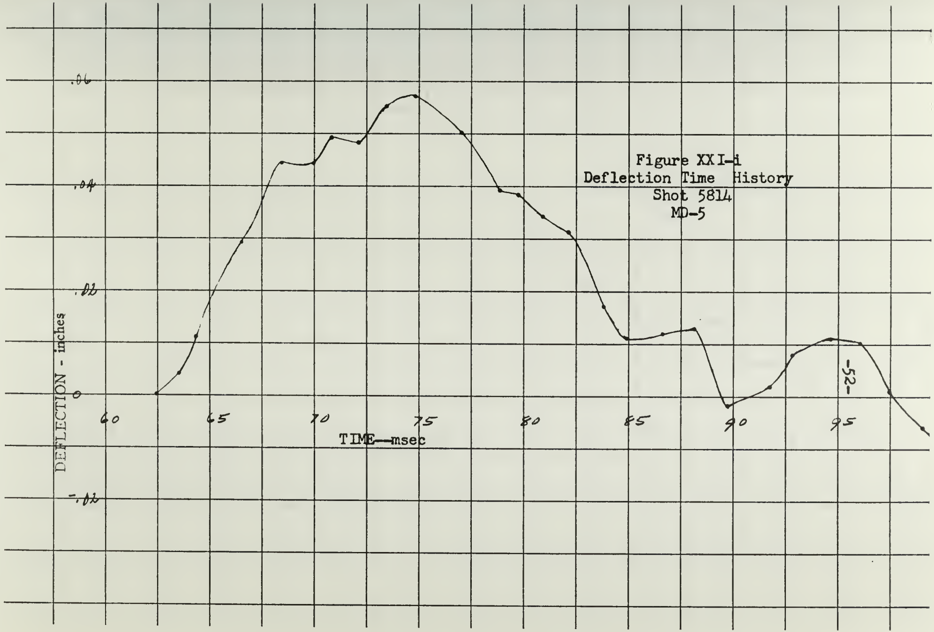


Figure XXI-1
Deflection Time History
Shot 5814
MD-5
DEFLECTION - inches
.06
.04
.02
0
-.02
60
65
70
75
80
85
90
95
TIME—msec

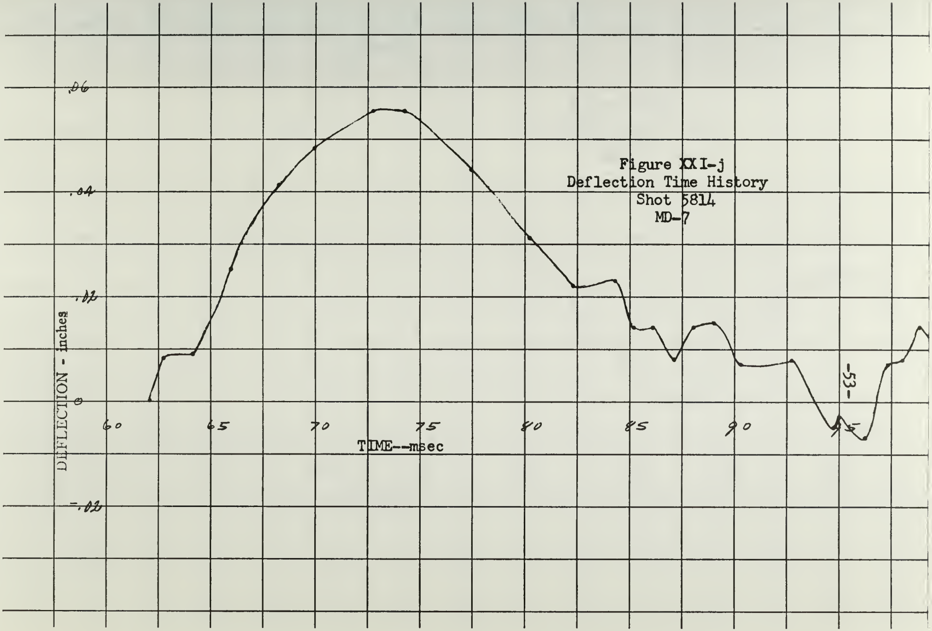


Figure XXI-j
Deflection Time History
Shot 5814
MD-7

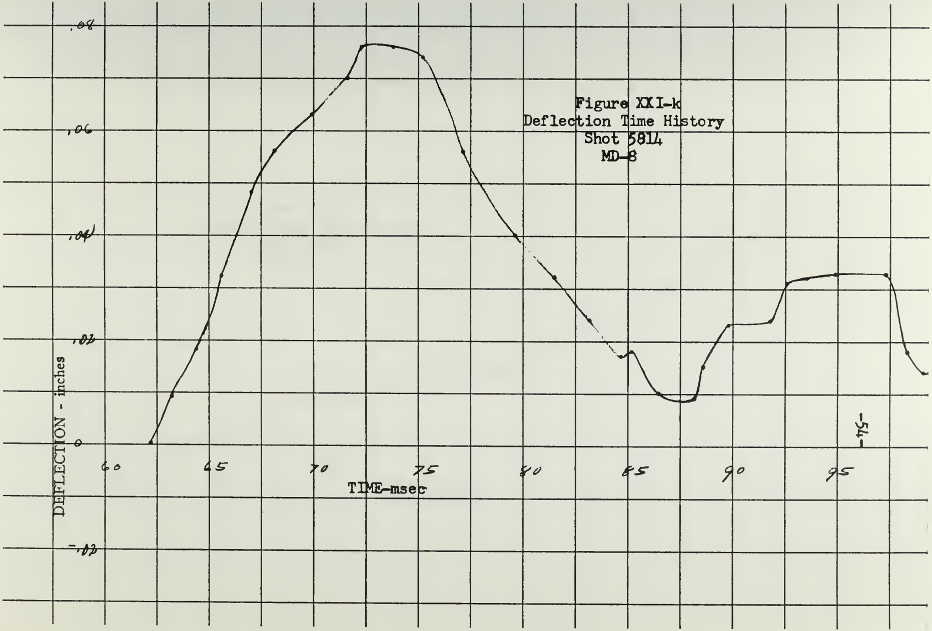


Figure XXI-k
Deflection Time History
Shot 5814
MD-8

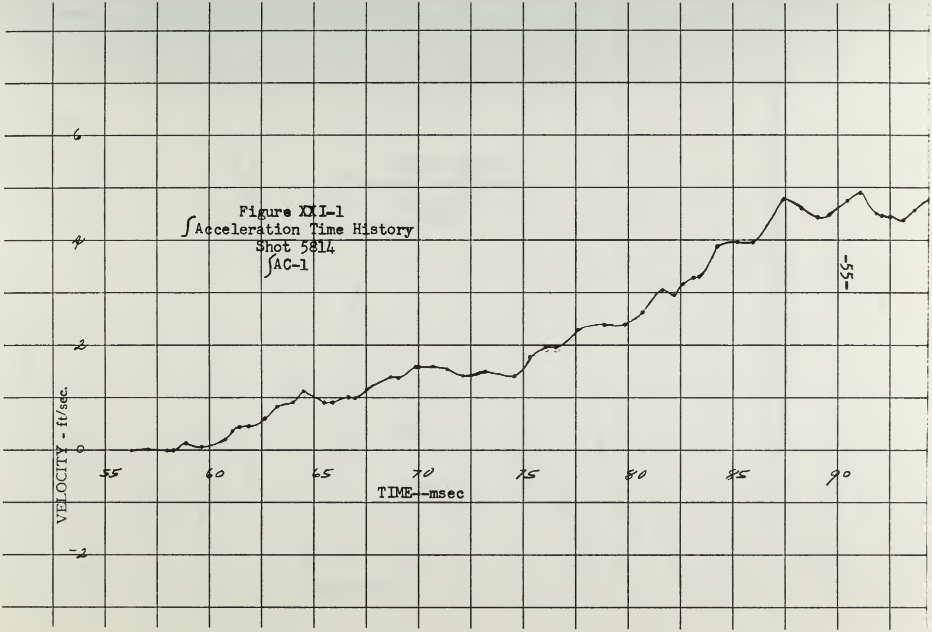


Figure XXI-1
∫Acceleration Time History
Shot 5814
∫AC-1

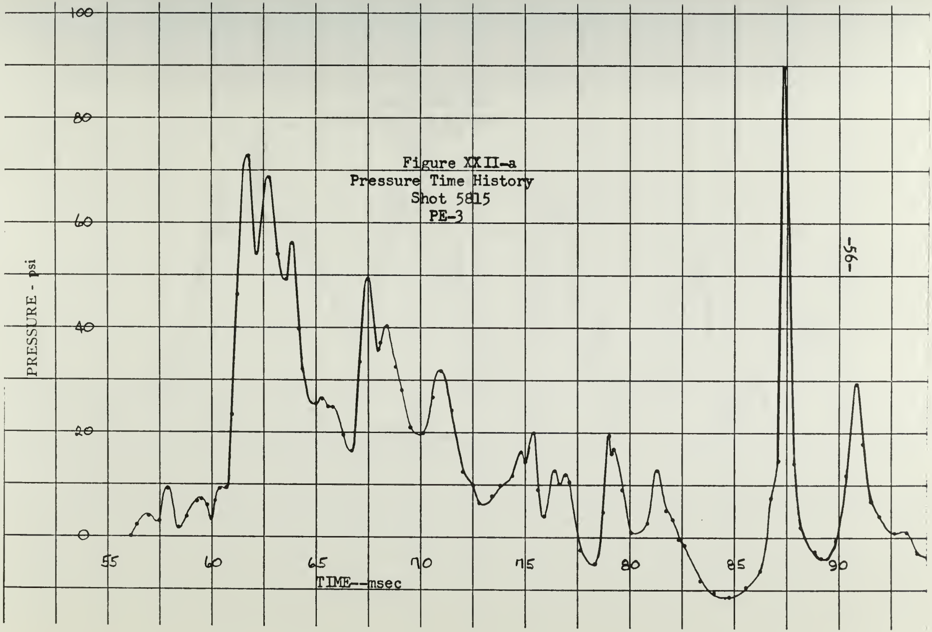


Figure XXII-a
Pressure Time History
Shot 5815
PE-3

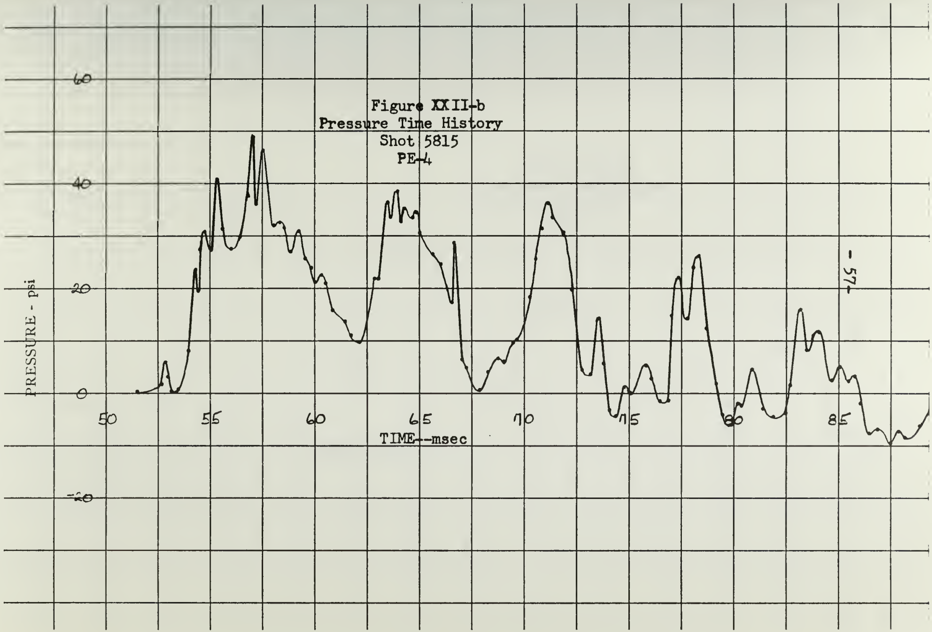


Figure XXII-b
Pressure Time History
Shot 5815
PE-4
PRESSURE - psi
60
40
20
0
-20
50
55
60
65
70
75
80
85
TIME--msec

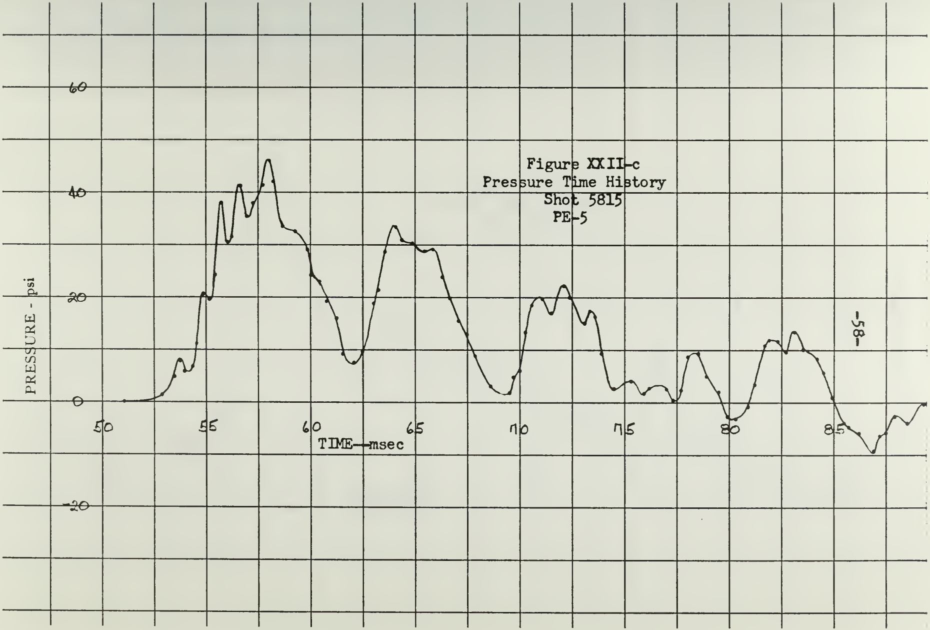


Figure XXII-c
Pressure Time History
Shot 5815
PE-5

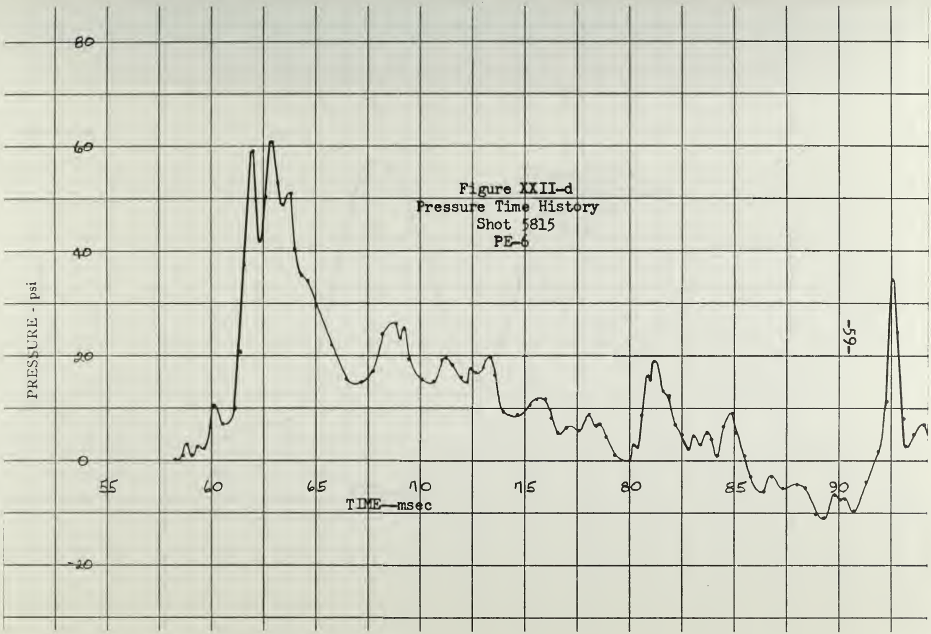


Figure XXII-d
Pressure Time History
Shot 5815
PE-6

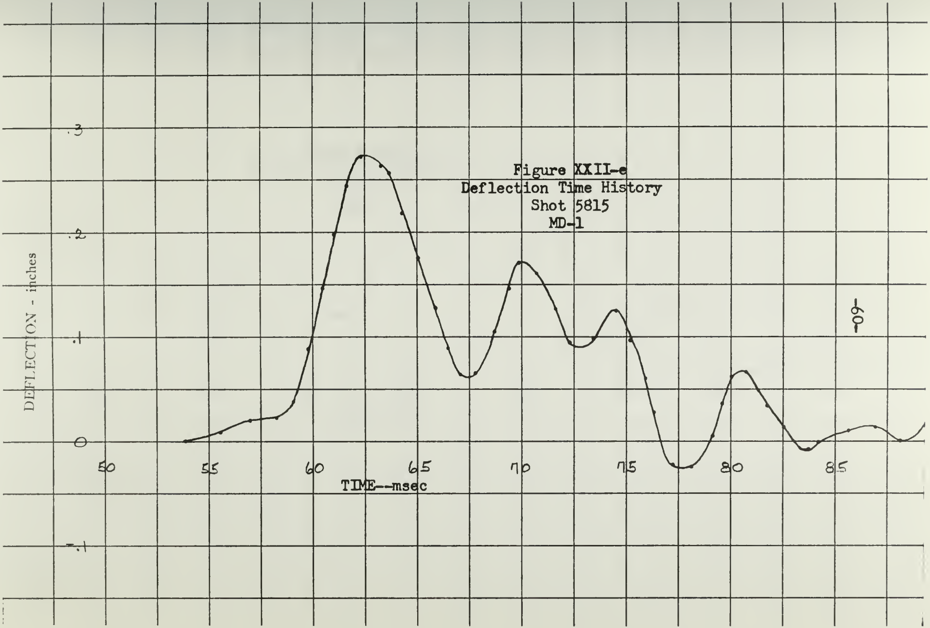


Figure XXII-e
Deflection Time History
Shot 5815
MD-1

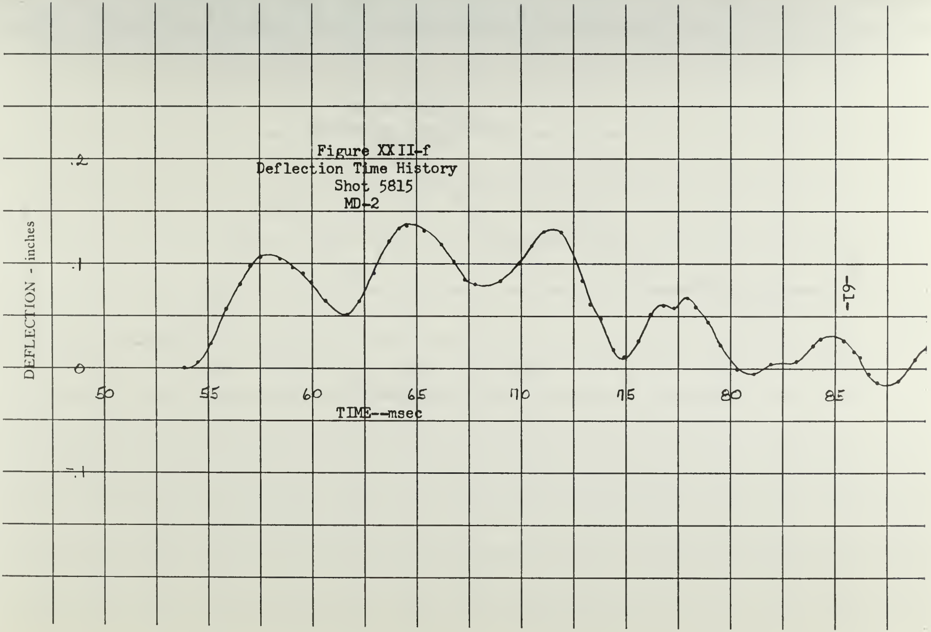
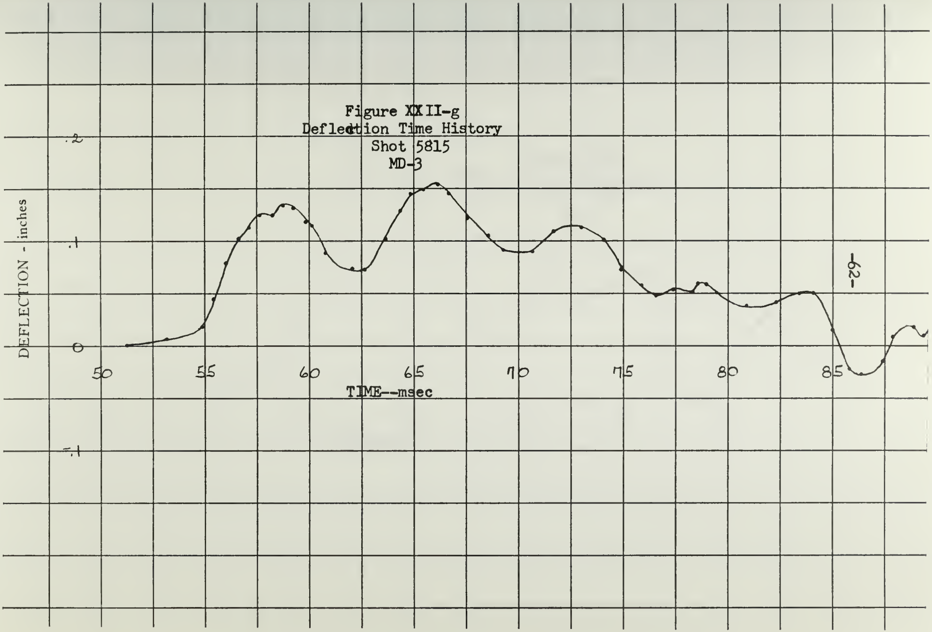


Figure XXII-f
Deflection Time History
Shot 5815
MD-2

Figure XXII-g
Deflection Time History
Shot 5815
MD-3



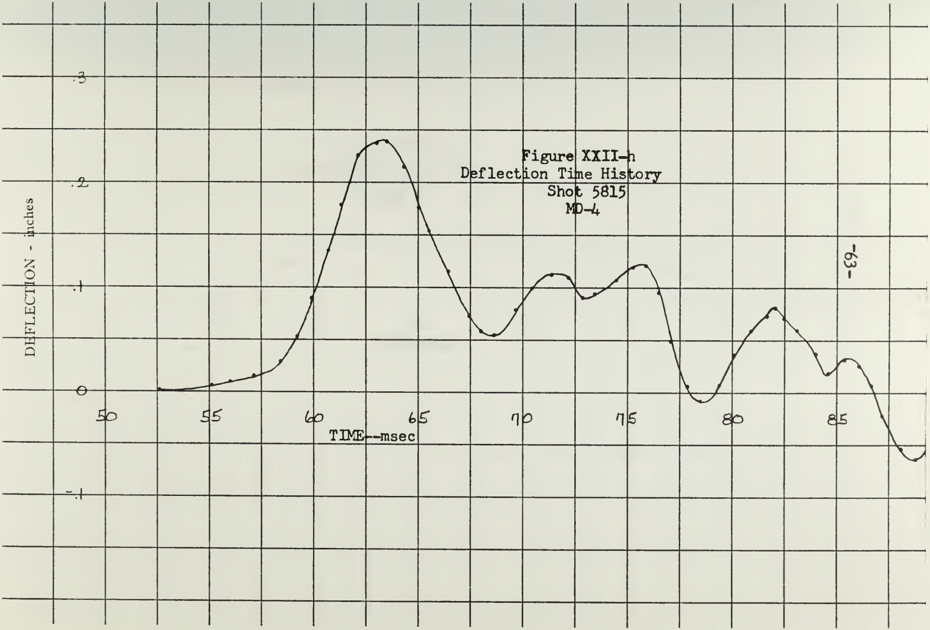


Figure XXII-h
Deflection Time History
Shot 5815
MD-4

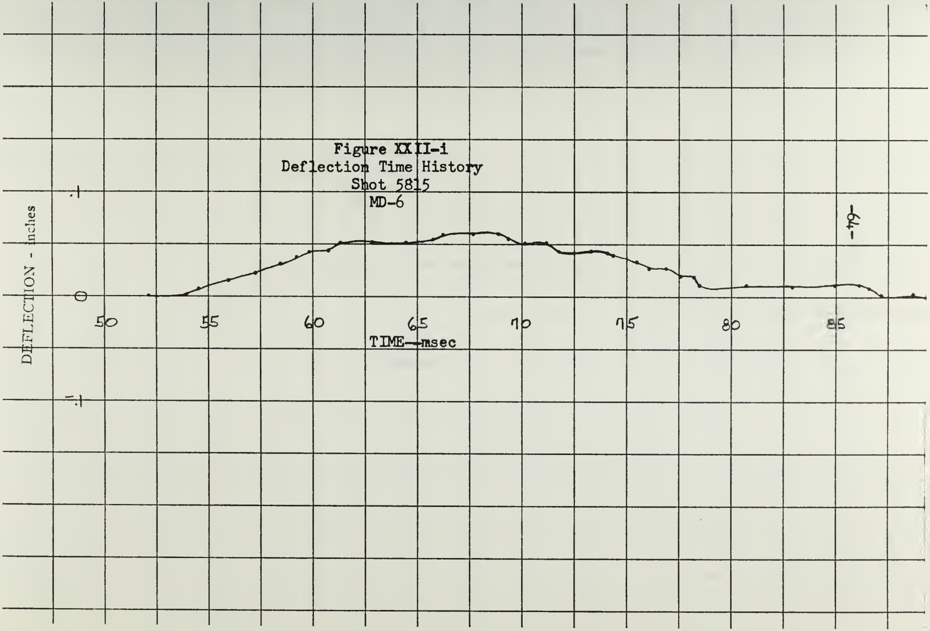


Figure XXII-i
Deflection Time History
Shot 5815
MD-6

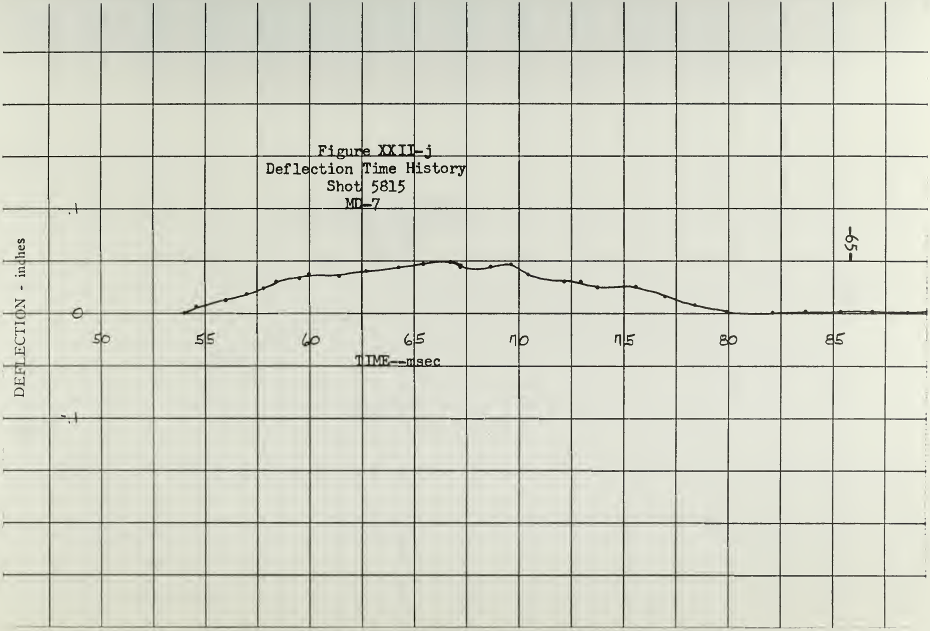


Figure XXII-j
Deflection Time History
Shot 5815
MD-7

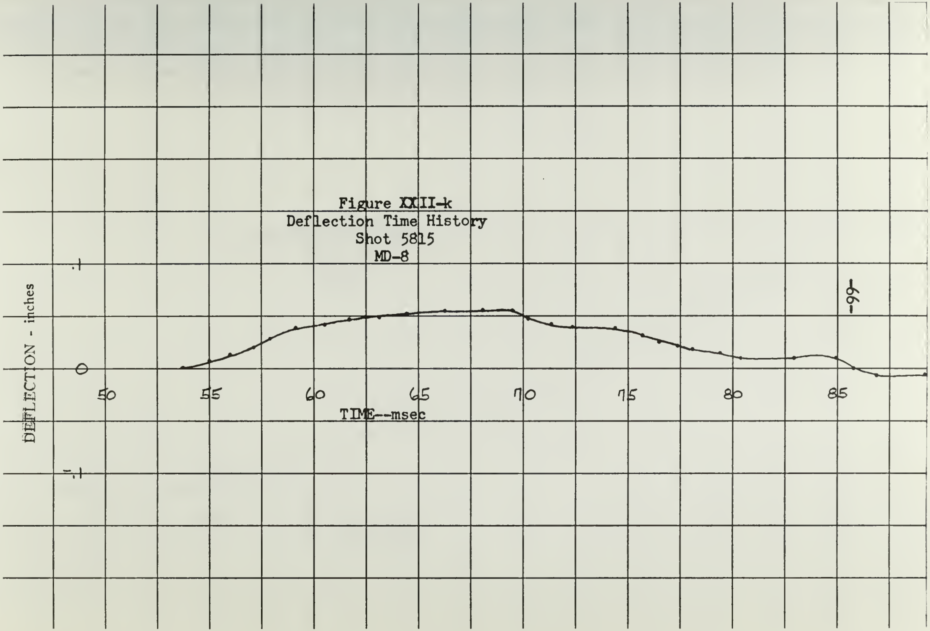


Figure XXII-k
Deflection Time History
Shot 5815
MD-8

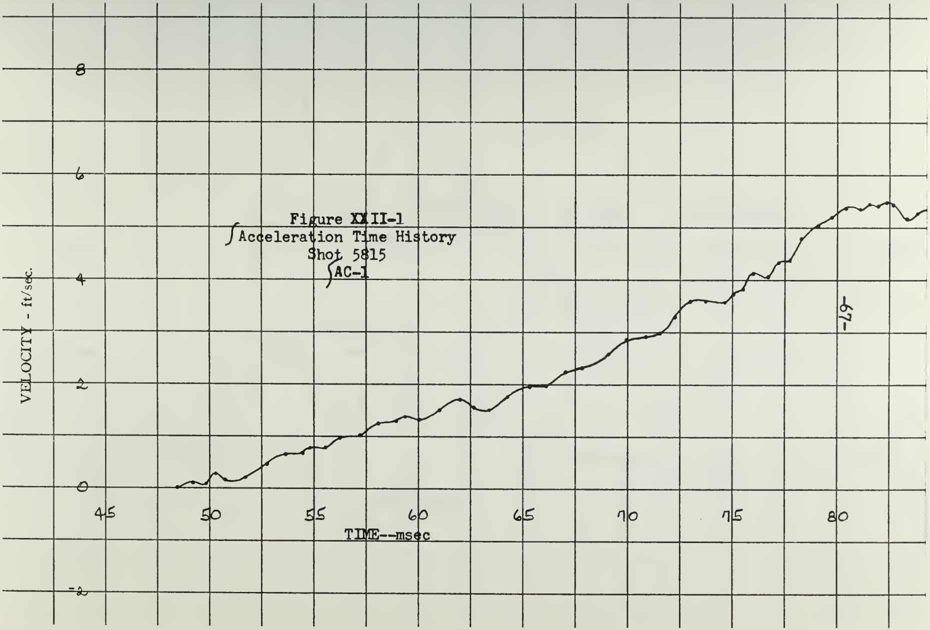


Figure XXII-1
∫Acceleration Time History
Shot 5815
∫AC-1

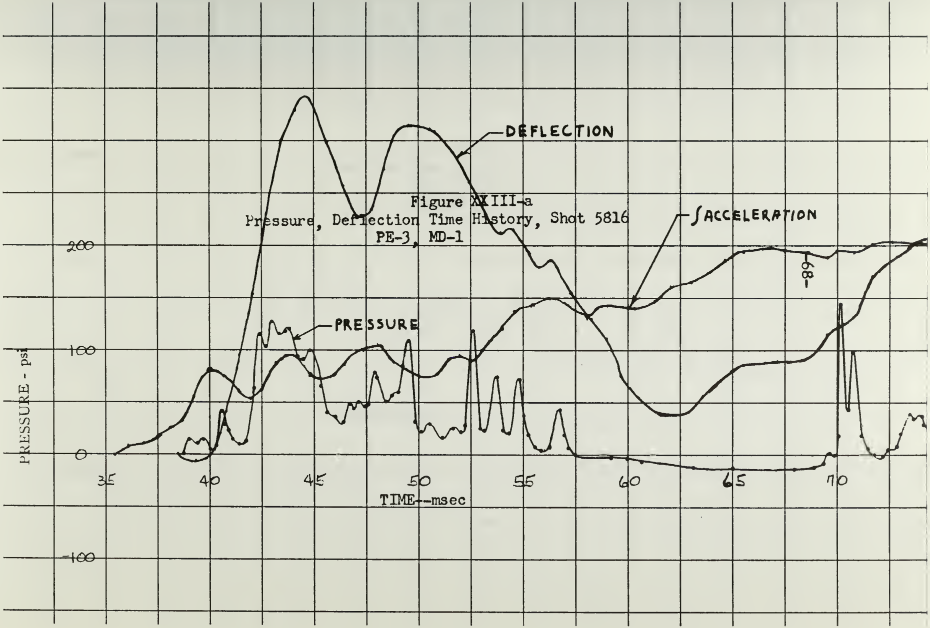


Figure XXIII-a
Pressure, Deflection Time History, Shot 5816
PE-3, MD-1

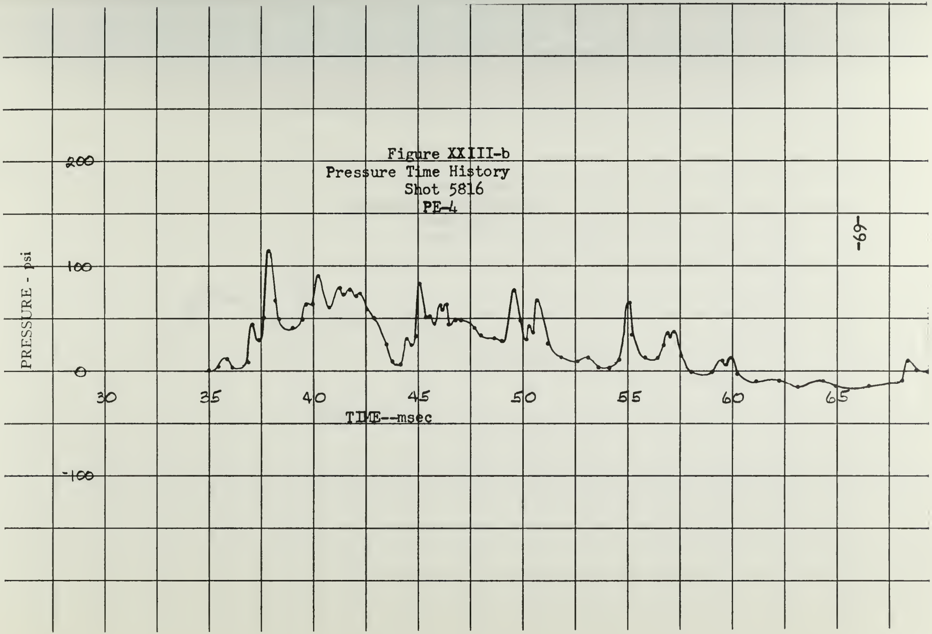


Figure XXIII-b
Pressure Time History
Shot 5816
PE-4

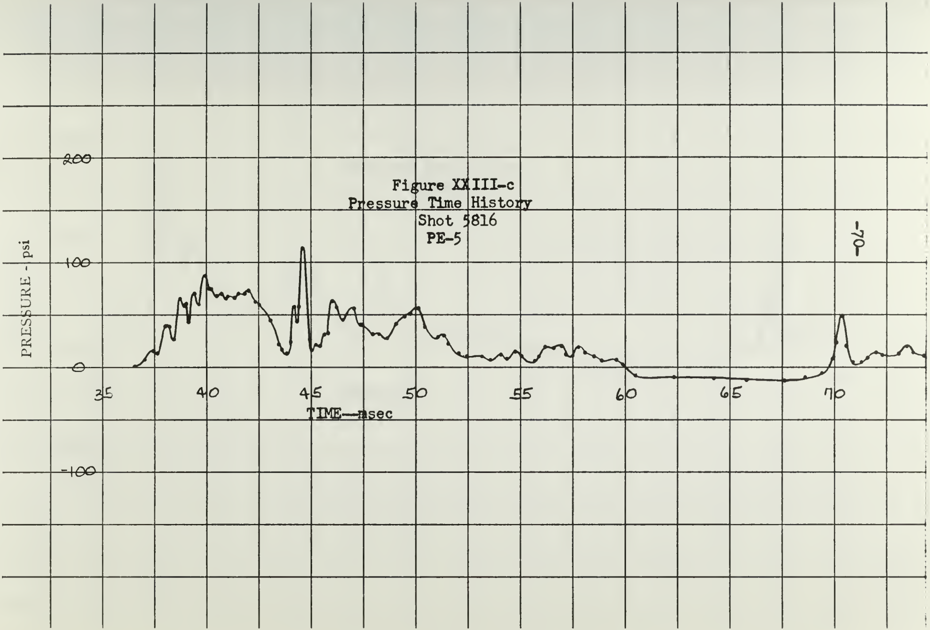


Figure XXIII-c
Pressure Time History
Shot 5816
PE-5

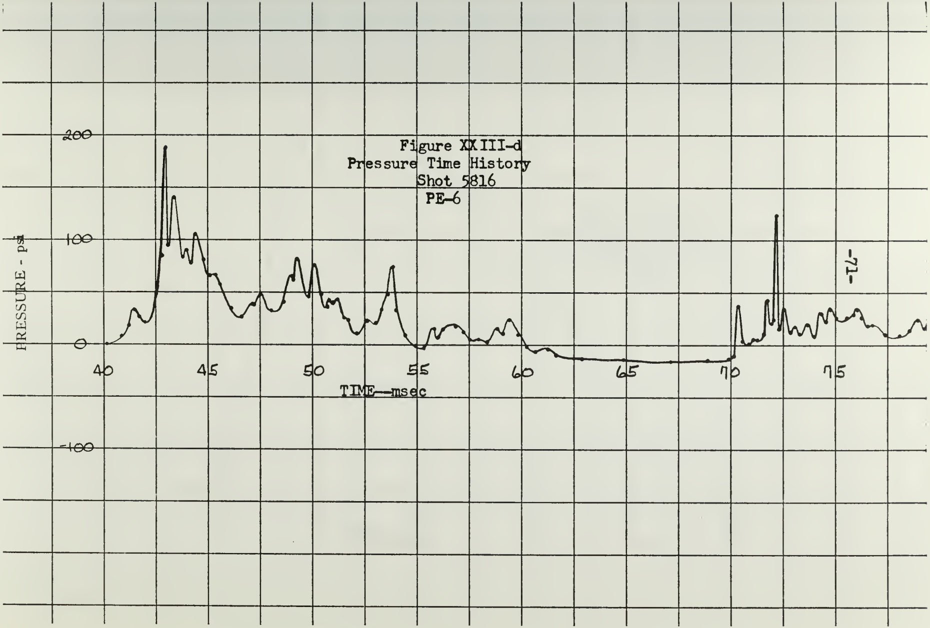


Figure XXIII-d
Pressure Time History
Shot 5816
PE-6

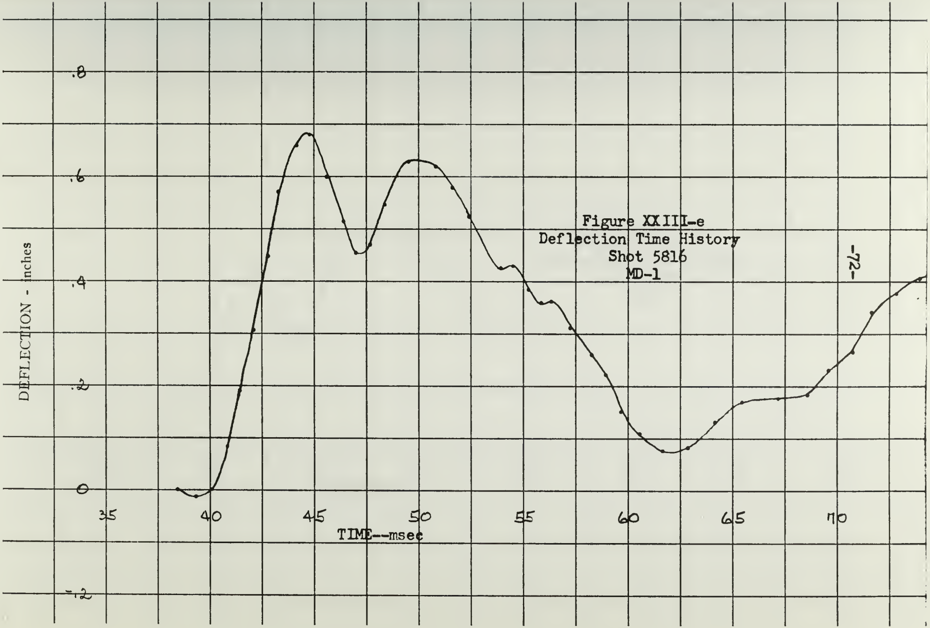


Figure XXIII-e
Deflection Time History
Shot 5816
MD-1

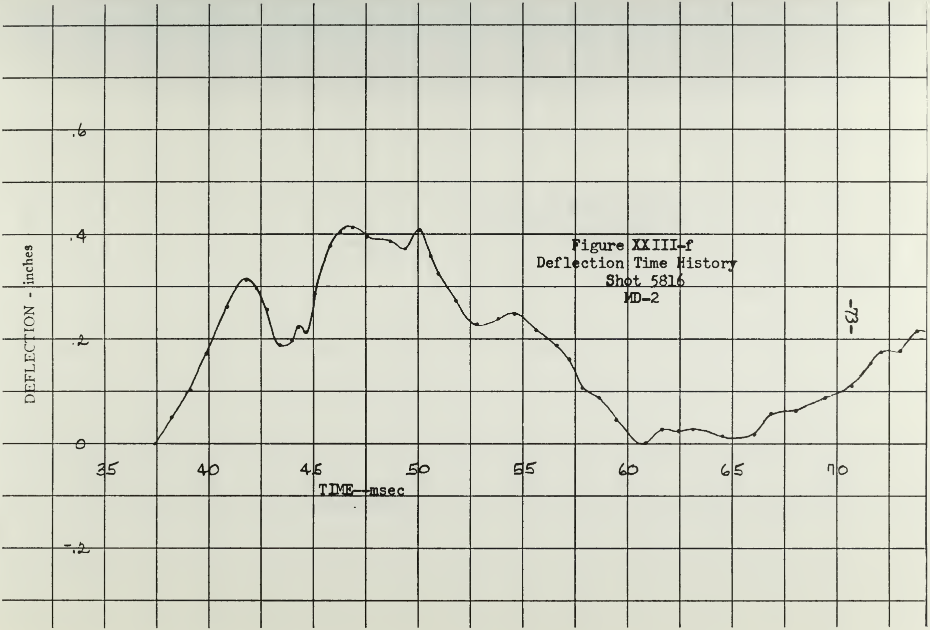


Figure XXIII-f
Deflection Time History
Shot 5816
MD-2

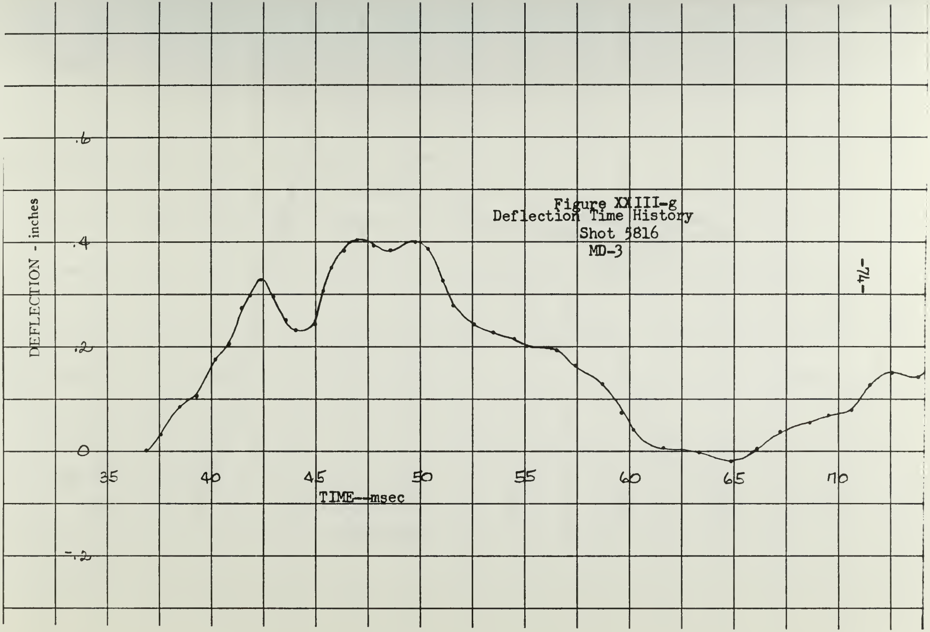


Figure XXIII-g
Deflection Time History
Shot 5816
MD-3

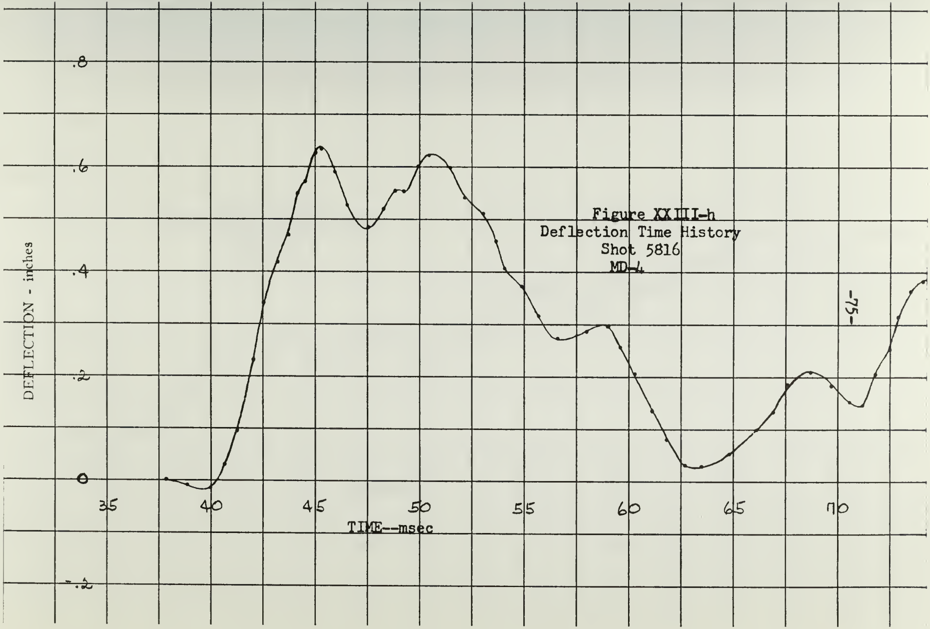


Figure XXIII-h
Deflection Time History
Shot 5816
MD-4

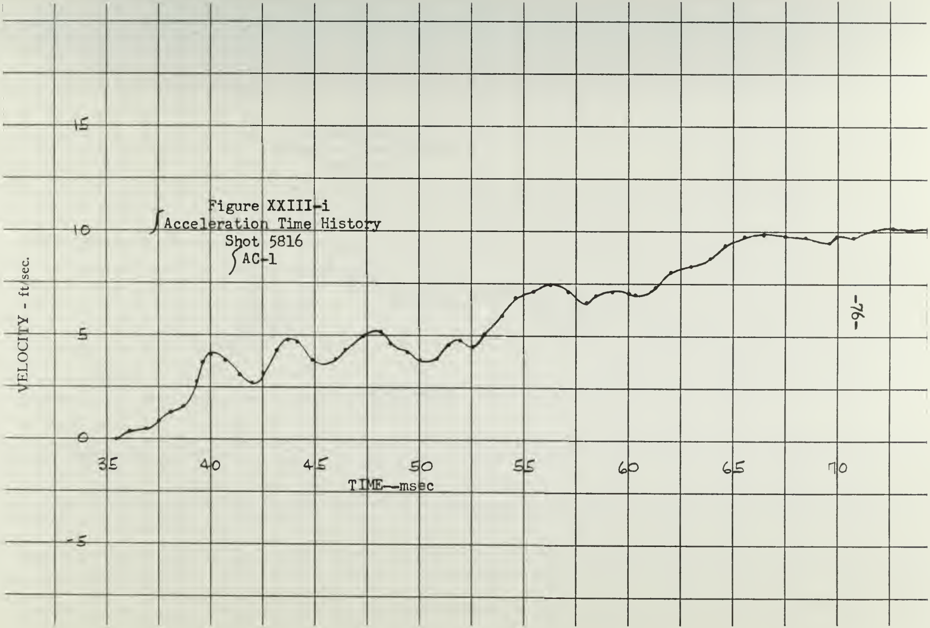


Figure XXIII-i
∫Acceleration Time History
Shot 5816
∫AC-1

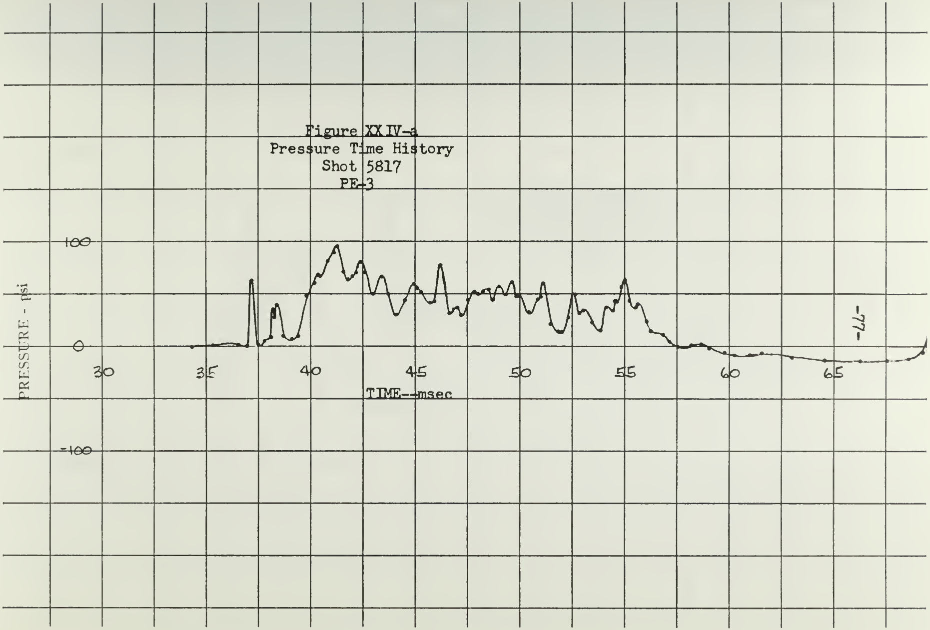


Figure XXIV-a
Pressure Time History
Shot 5817
PE-3

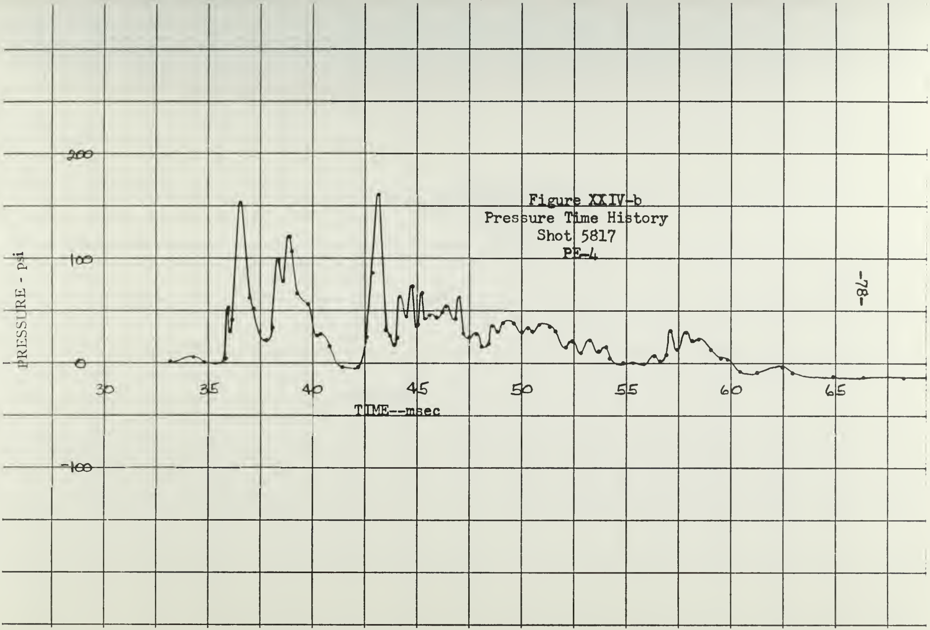


Figure XXIV-b
Pressure Time History
Shot 5817
PE-4

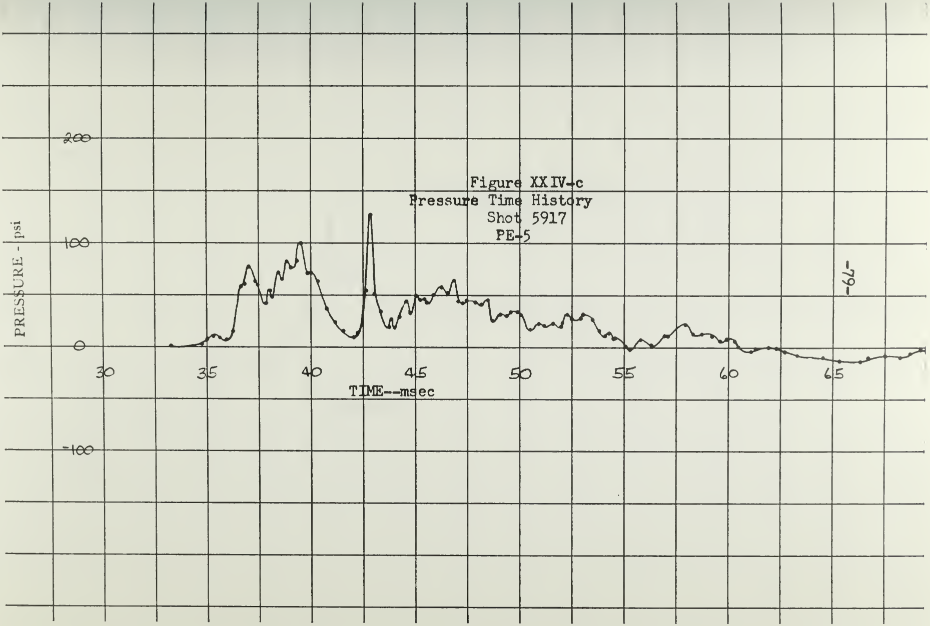


Figure XXIV-c
Pressure Time History
Shot 5917
PE-5

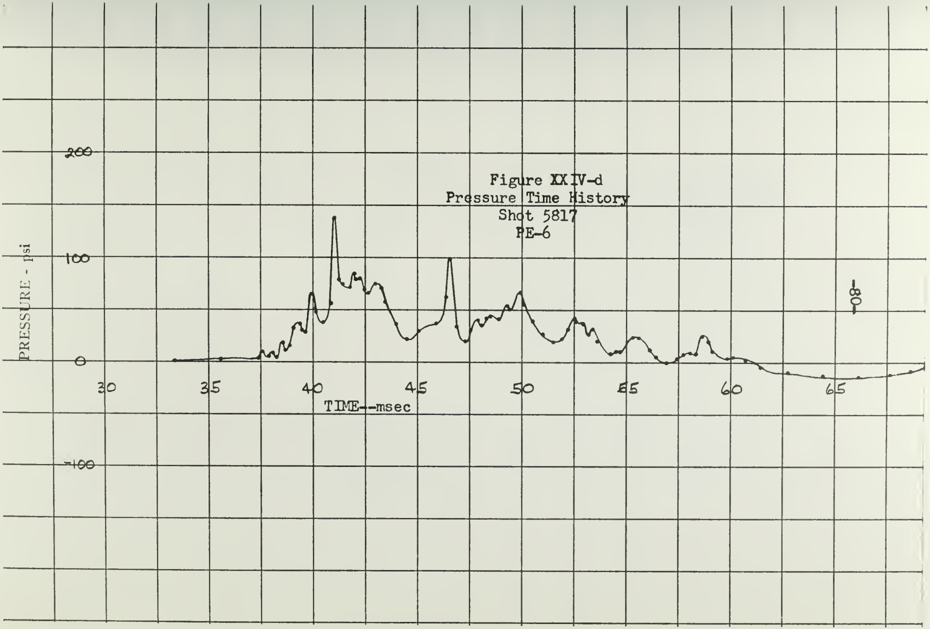


Figure XXIV-d
Pressure Time History
Shot 5817
PE-6
PRESSURE - psi
200
100
0
-100
30
35
40
45
50
55
60
65
TIME--msec
-80-

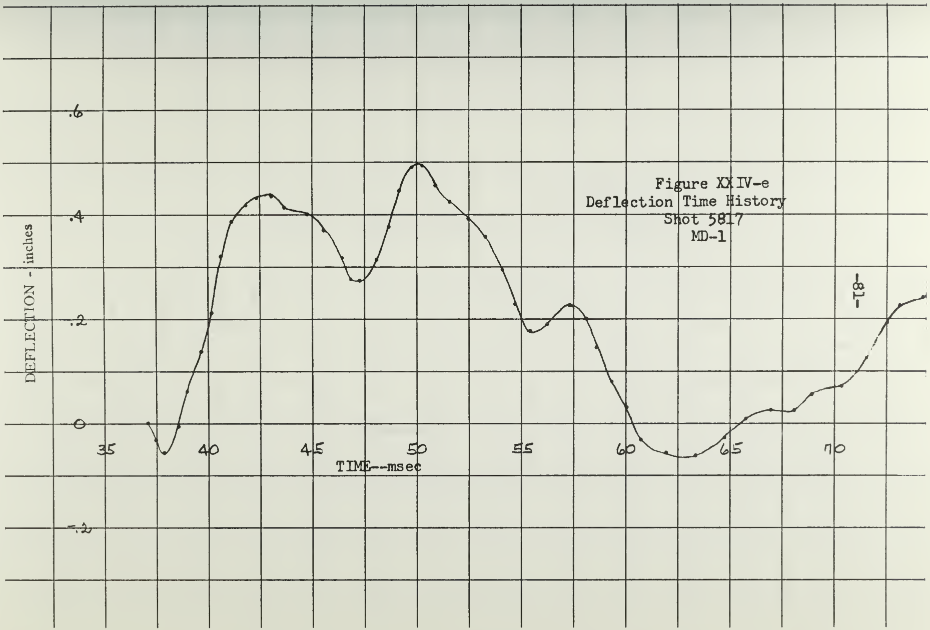


Figure XXIV-e
Deflection Time History
Shot 5817
MD-1

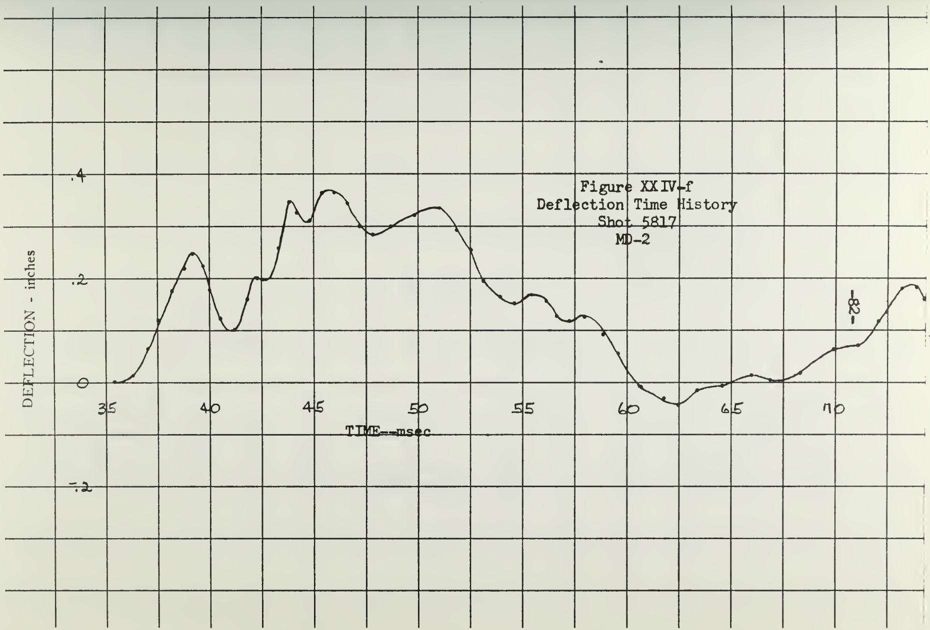


Figure XXIV-f
Deflection Time History
Shot 5817
MD-2

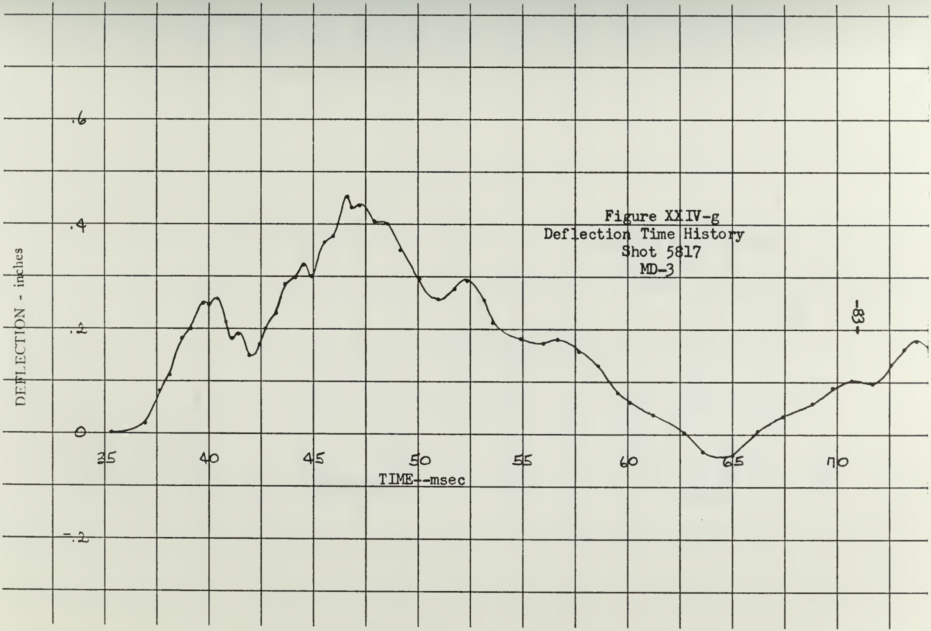


Figure XXIV-g
Deflection Time History
Shot 5817
MD-3

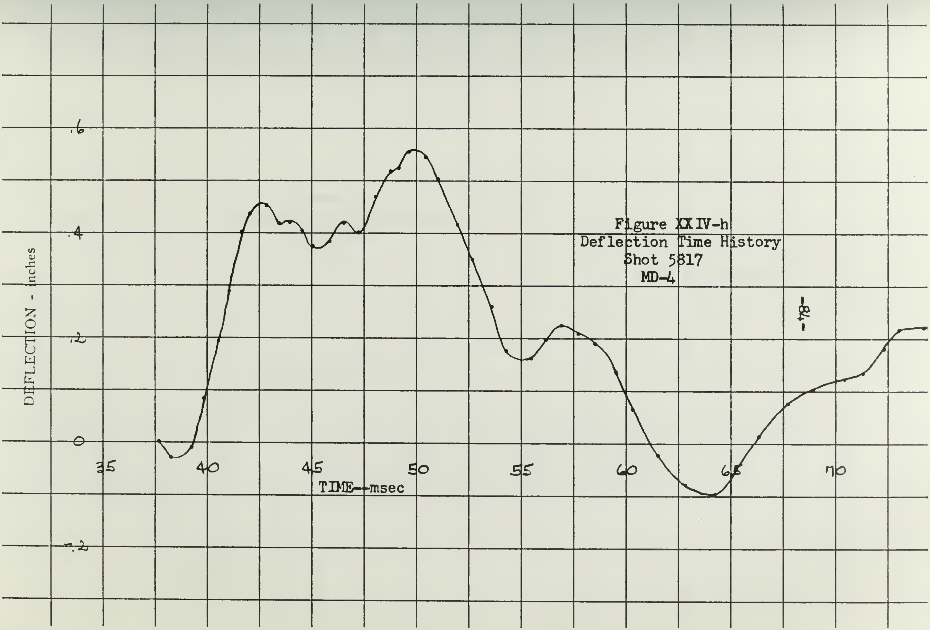


Figure XXIV-h
Deflection Time History
Shot 5817
MD-4

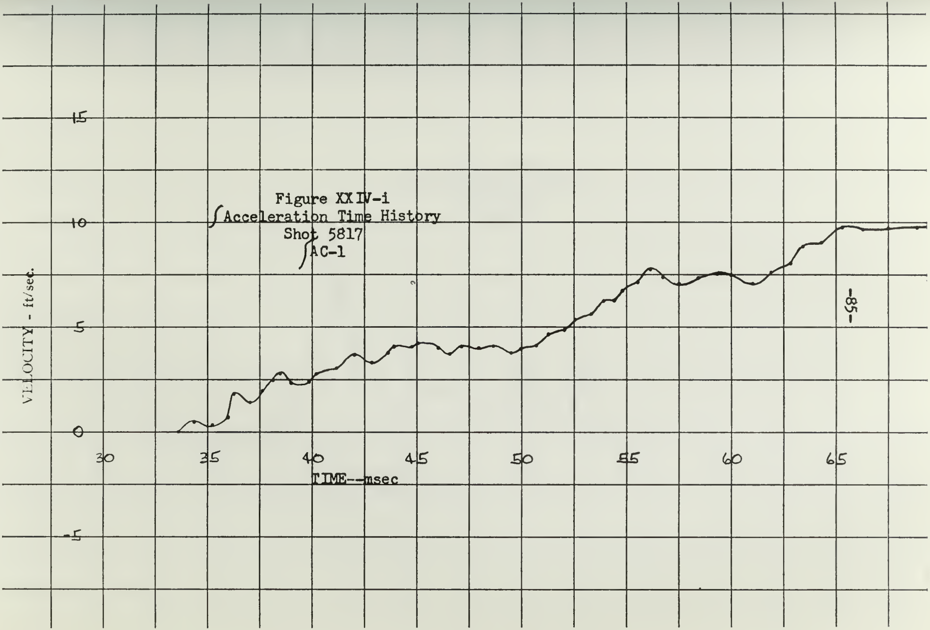


Figure XXIV-i
∫Acceleration Time History
Shot 5817
∫AC-1

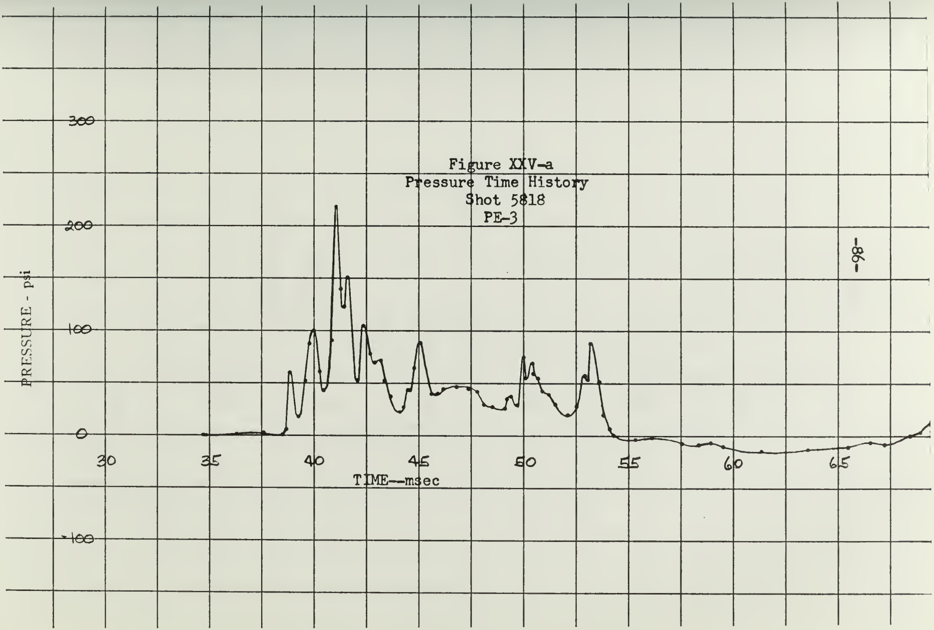


Figure XXV-a
Pressure Time History
Shot 5818
PE-3

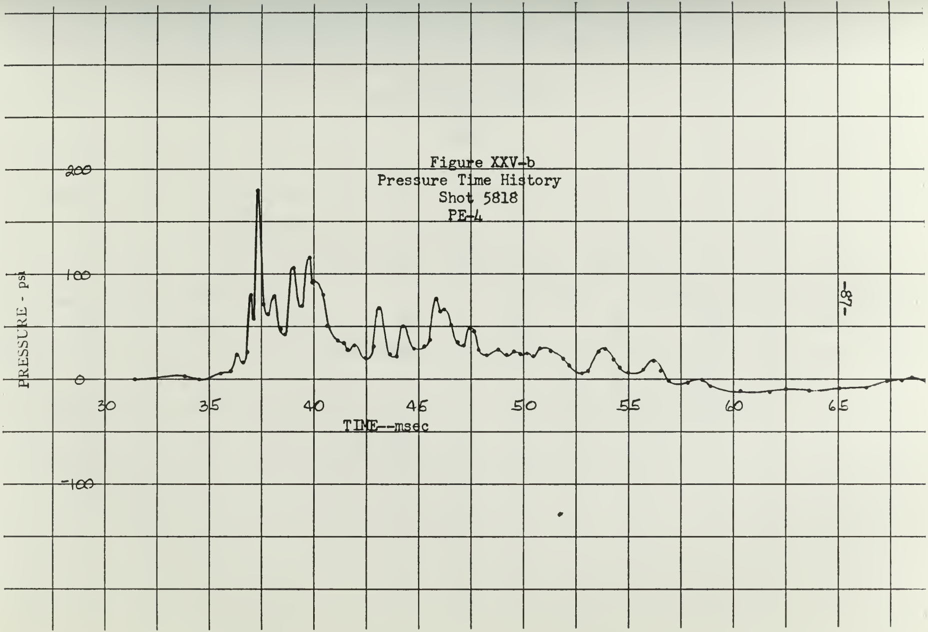


Figure XXV-b
Pressure Time History
Shot 5818
PE-4

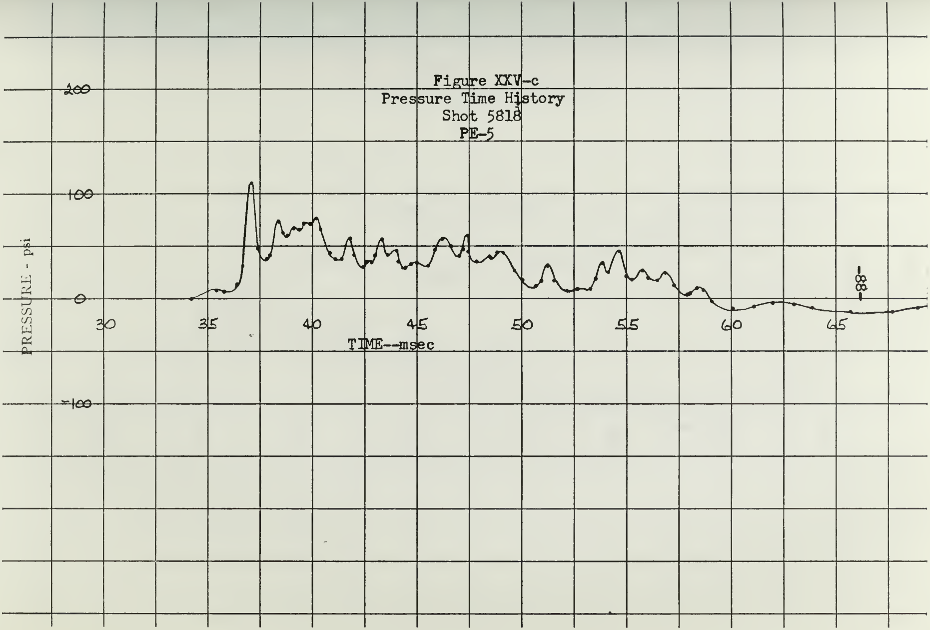


Figure XXV-c
Pressure Time History
Shot 5818
PE-5

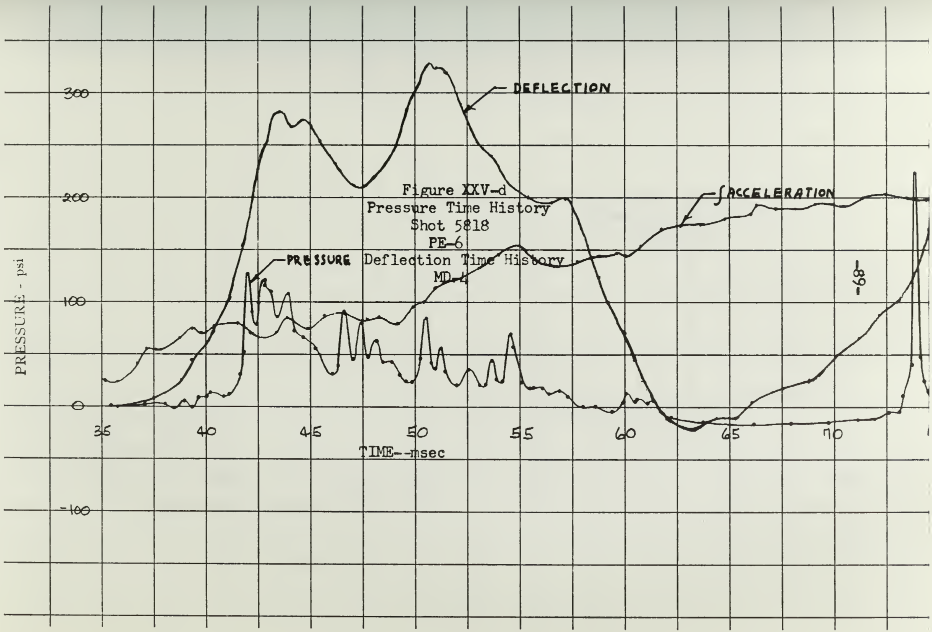


Figure XXV-d
Pressure Time History
Shot 5818
PE-6
Deflection Time History
MD-4

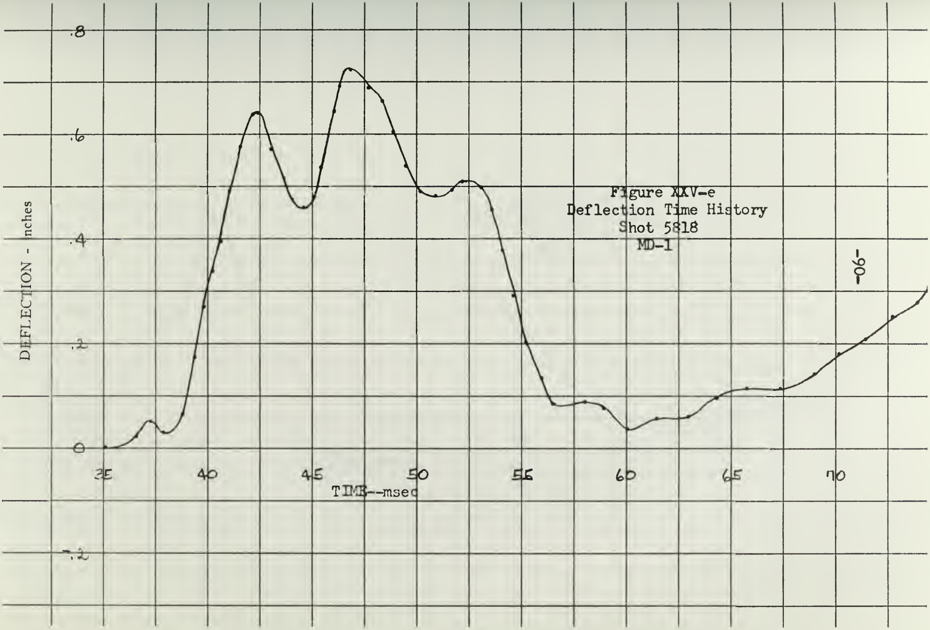


Figure XXV-e
Deflection Time History
Shot 5818
MD-1

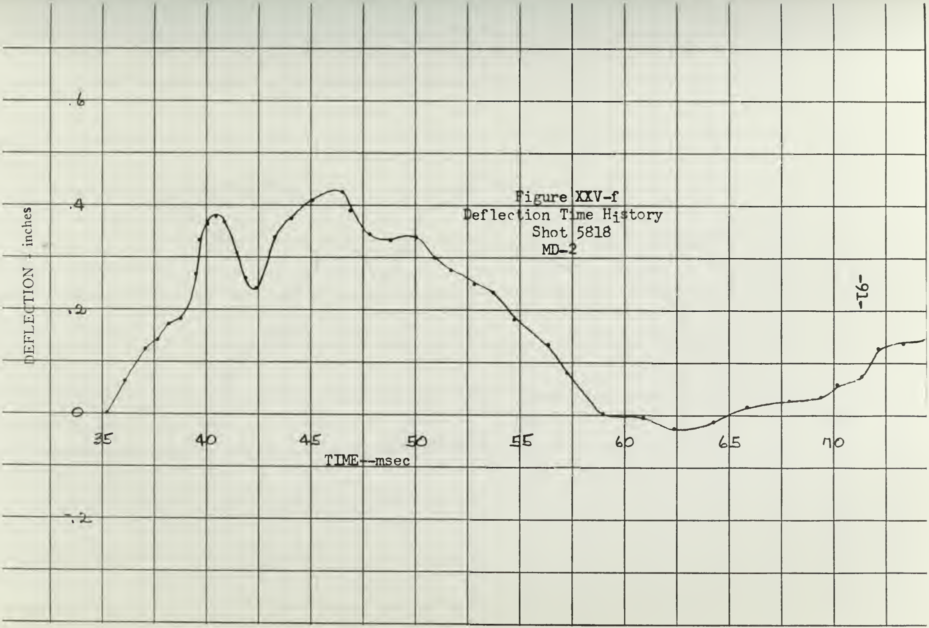


Figure XXV-f
Deflection Time History
Shot 5818
MD-2

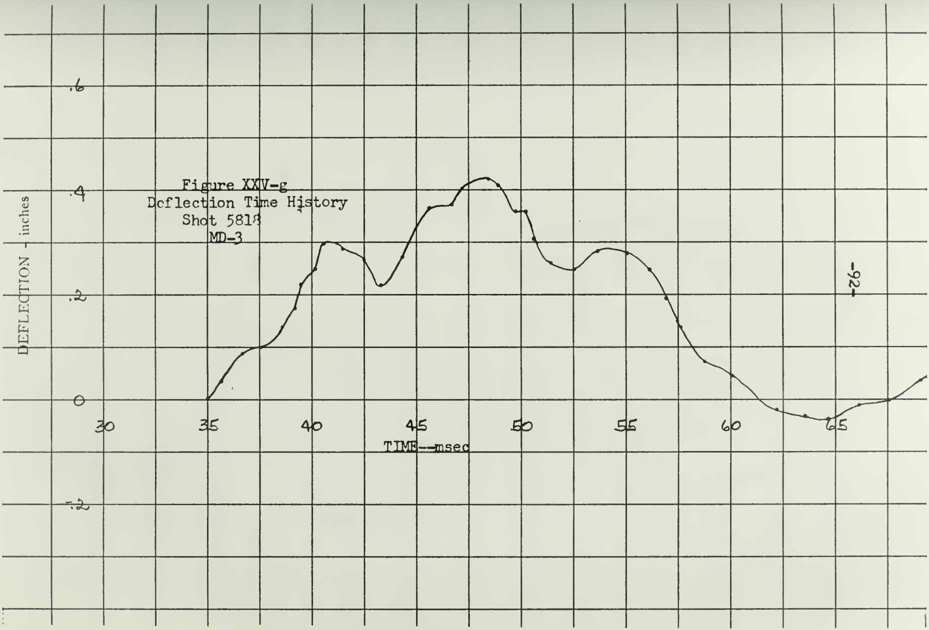
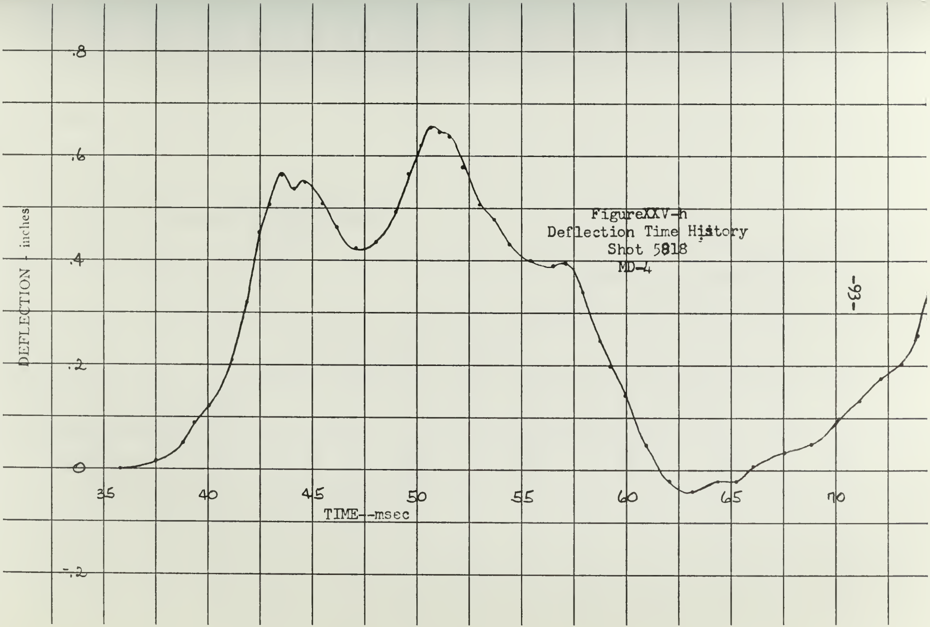


Figure XXV-g
Deflection Time History
Shot 5818
MD-3



FigureXXV-h
Deflection Time History
Shot 5818
MD-4

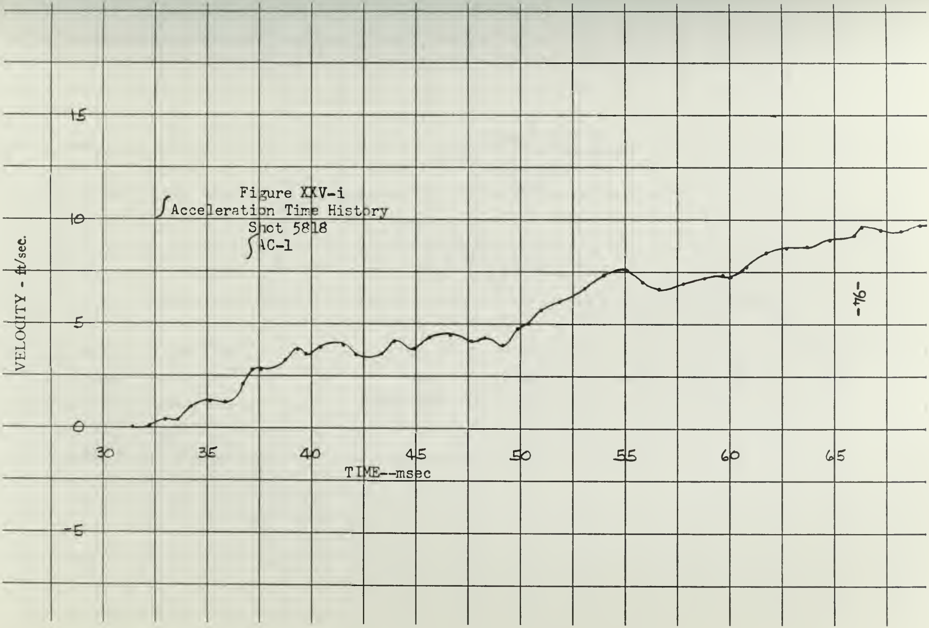


Figure XXV-i
∫Acceleration Time History
Shot 5818
∫AC-1

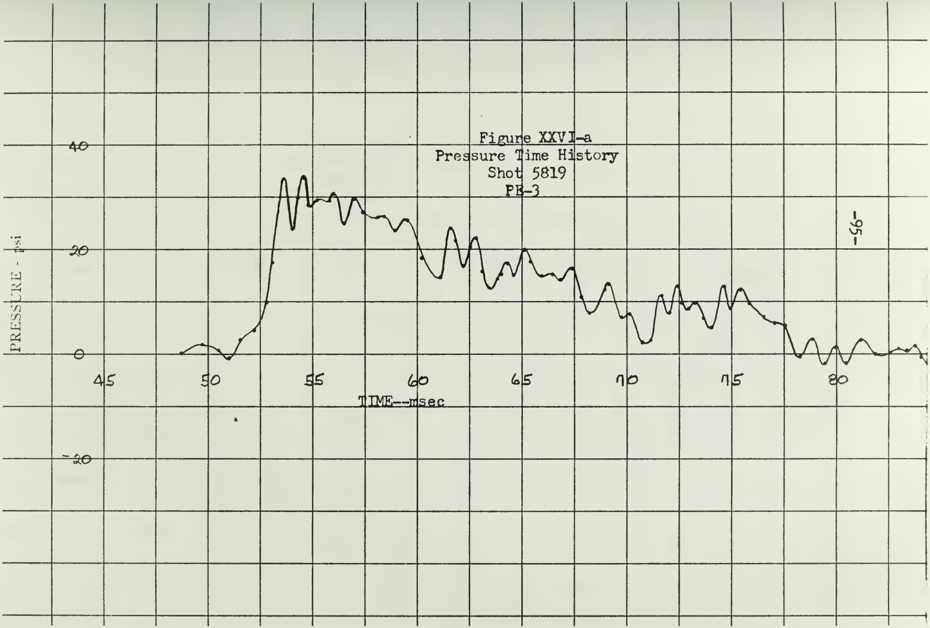


Figure XXVI-a
Pressure Time History
Shot 5819
PB-3

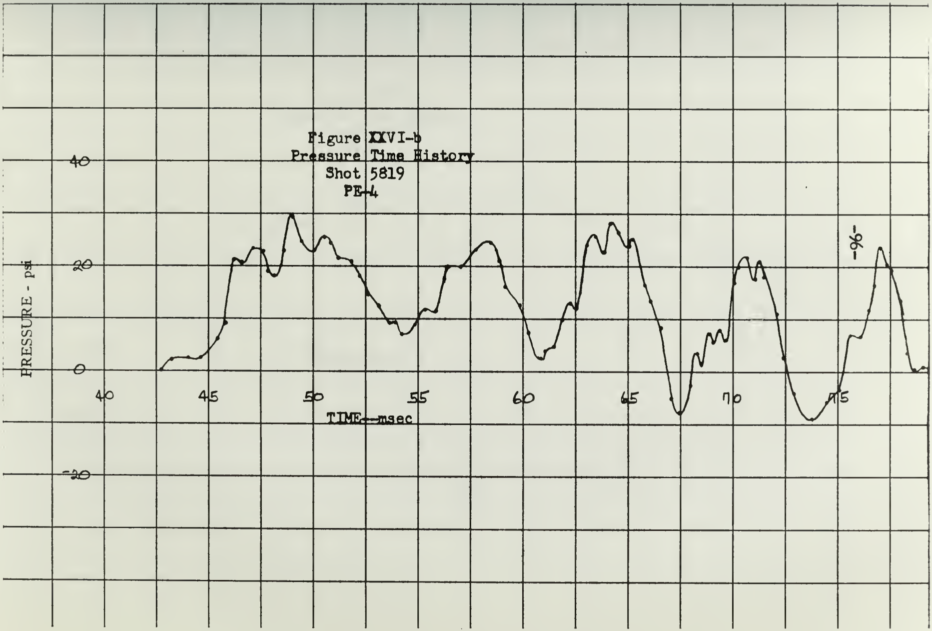


Figure XXVI-b
Pressure Time History
Shot 5819
PE-4
-96-
40
20
0
-20
PRESSURE - psi
40
45
50
55
60
65
70
75
TIME--msec

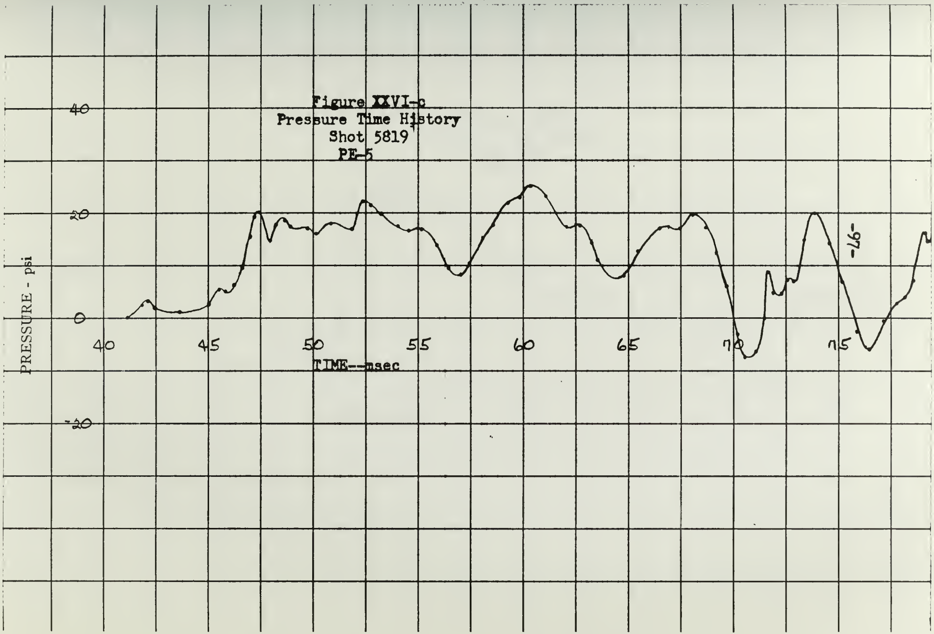


Figure XXVI-c
Pressure Time History
Shot 5819
PE-5
40
20
0
-20
PRESSURE - psi
40
45
50
55
60
65
70
75
TIME--msec

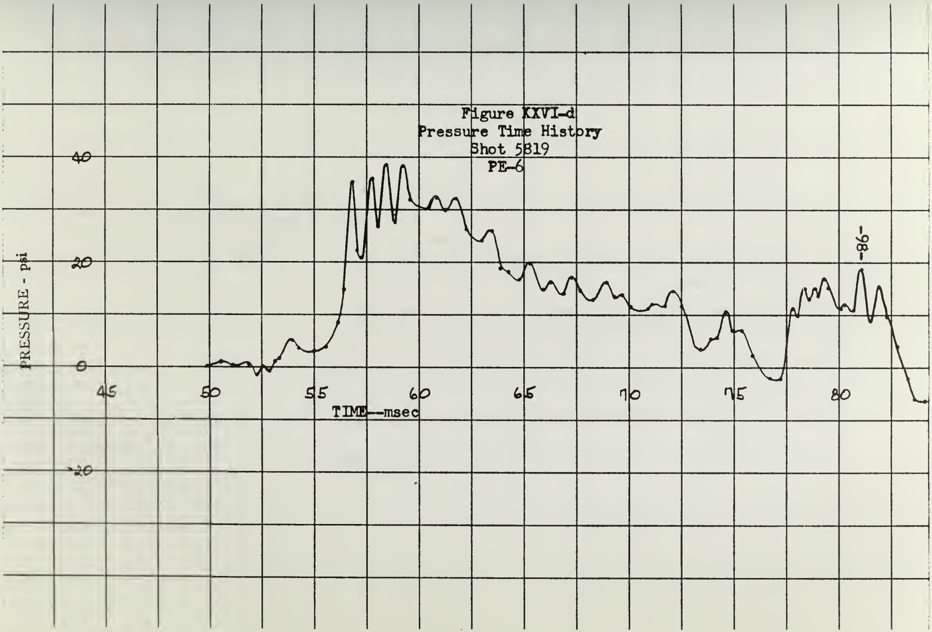


Figure XXVI-d
Pressure Time History
Shot 5819
PE-6

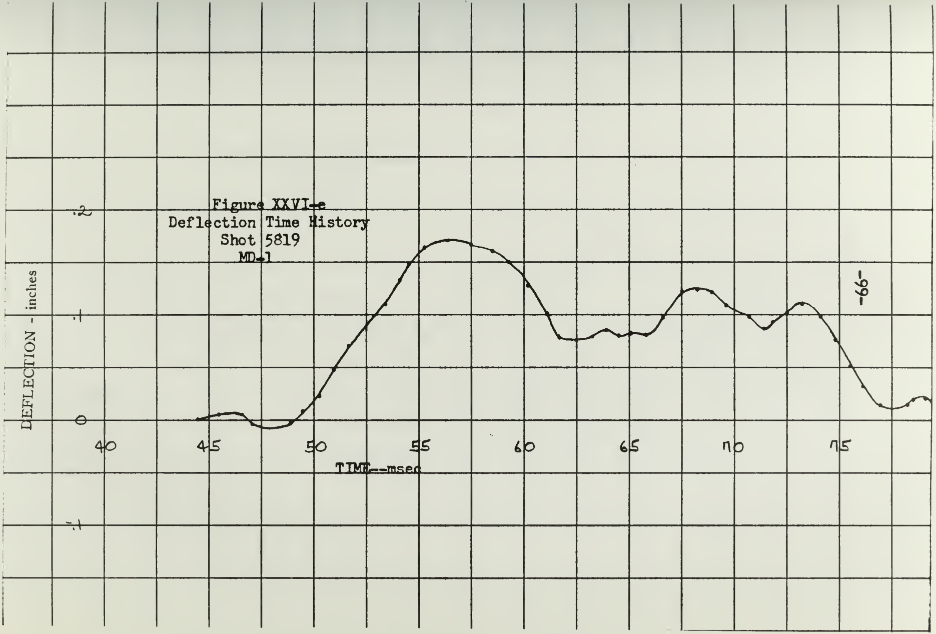


Figure XXVI-e
Deflection Time History
Shot 5819
MD-1

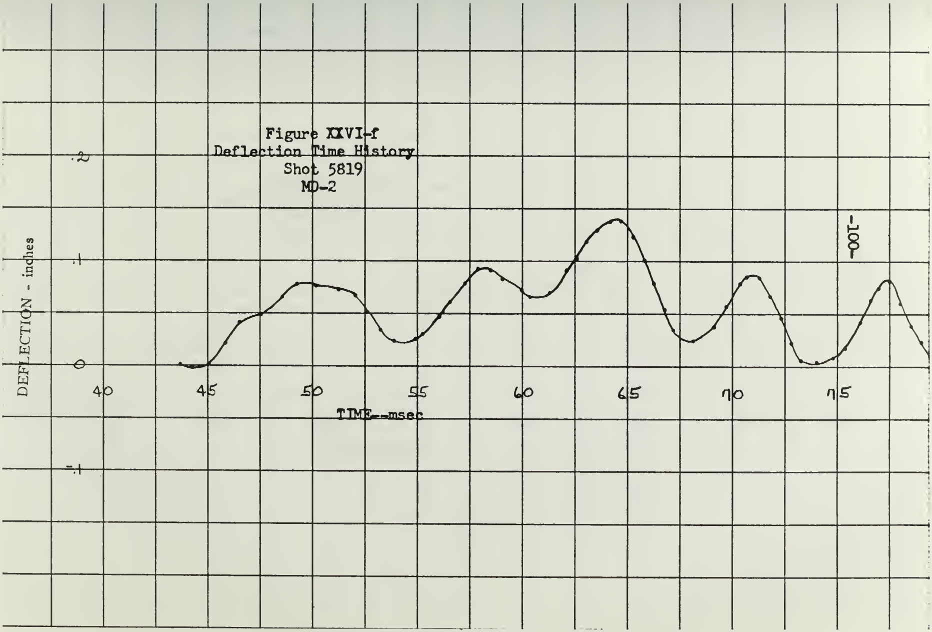


Figure XXVI-f
Deflection Time History
Shot 5819
MD-2

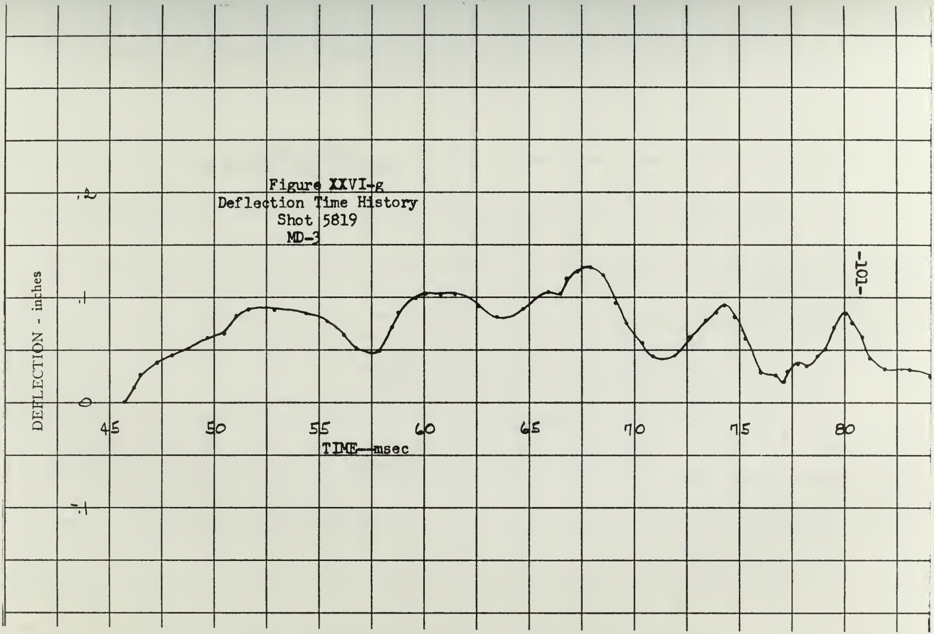


Figure XXVI-g
Deflection Time History
Shot 5819
MD-3

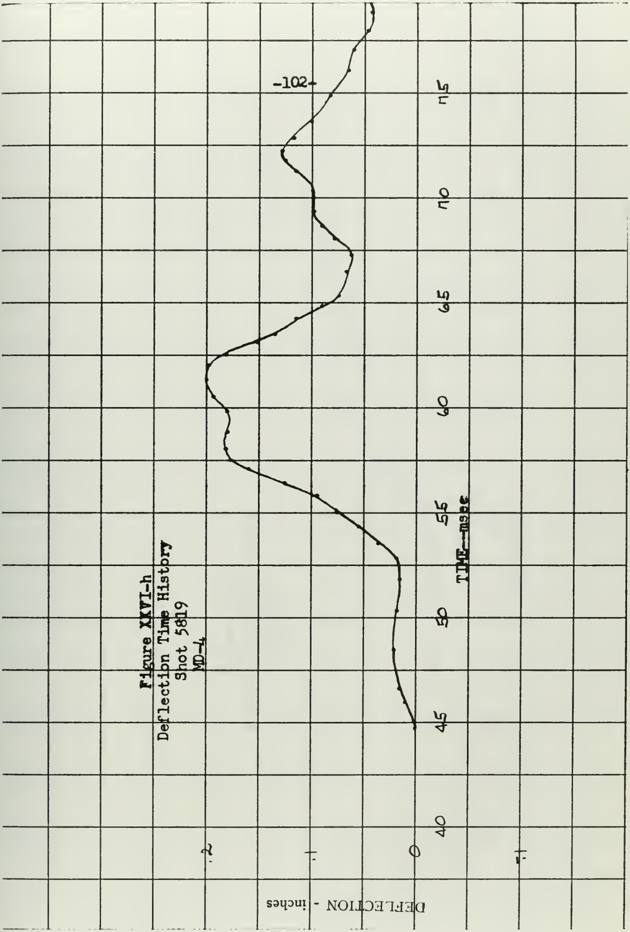


Figure XXVI-h
Deflection Time History
Shot 5819
MD-4

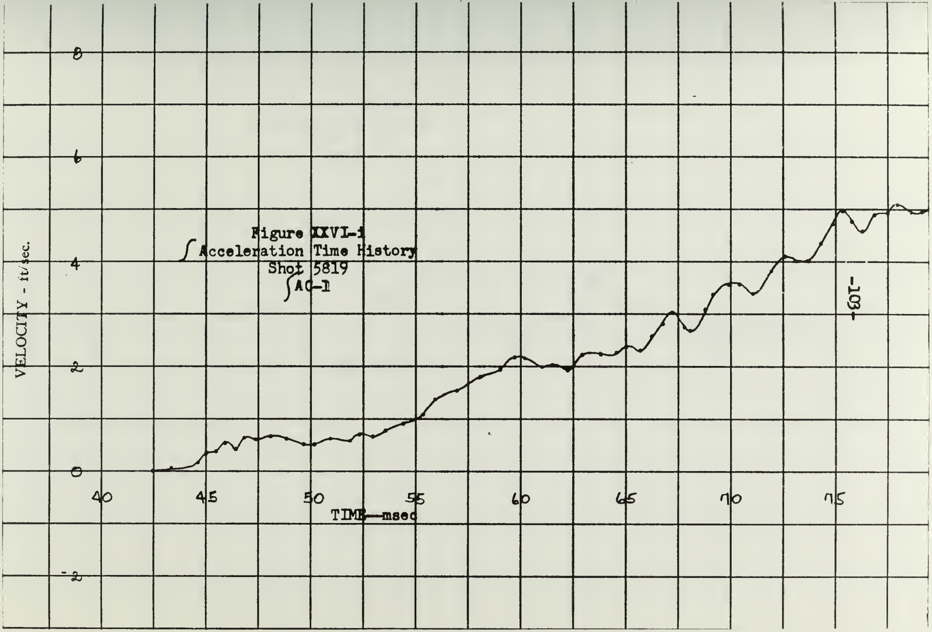


Figure XXVI-1
∫ Acceleration Time History
Shot 5819
∫ AC-1

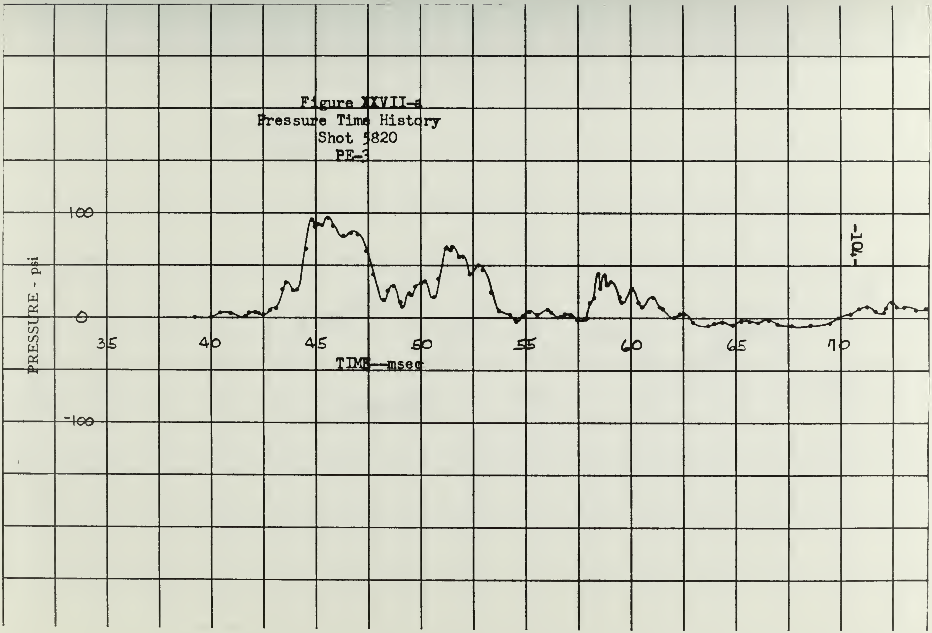


Figure XXVII-a
Pressure Time History
Shot 5820
PE-3

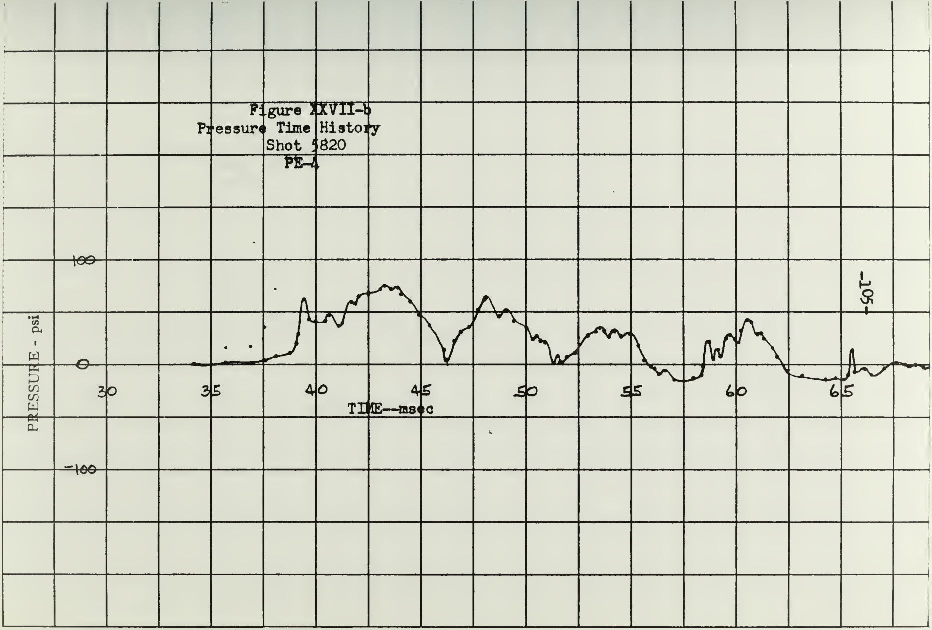


Figure XXVII-b
Pressure Time History
Shot 5820
PE-4

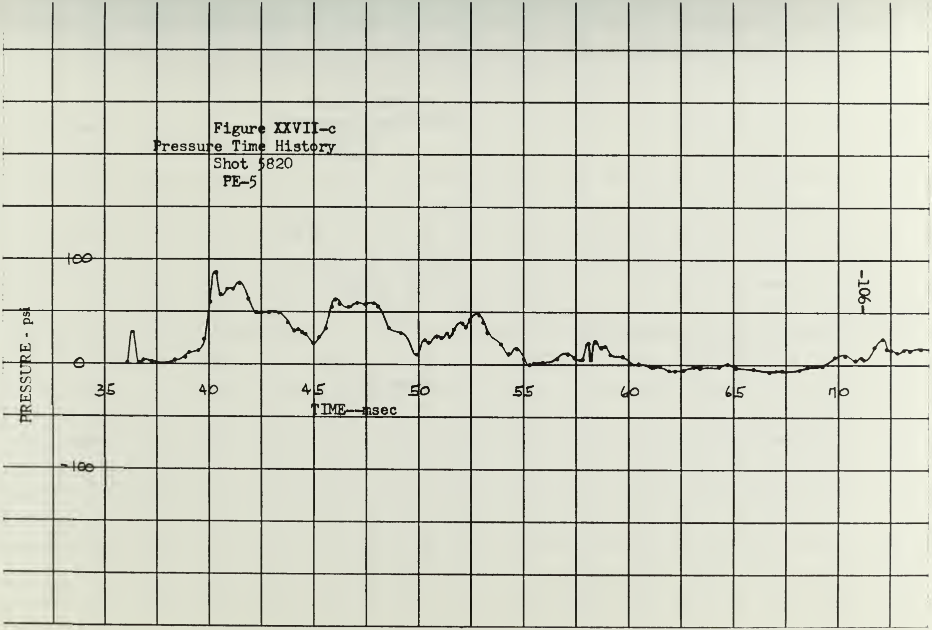


Figure XXVII-c
Pressure Time History
Shot 5820
PE-5

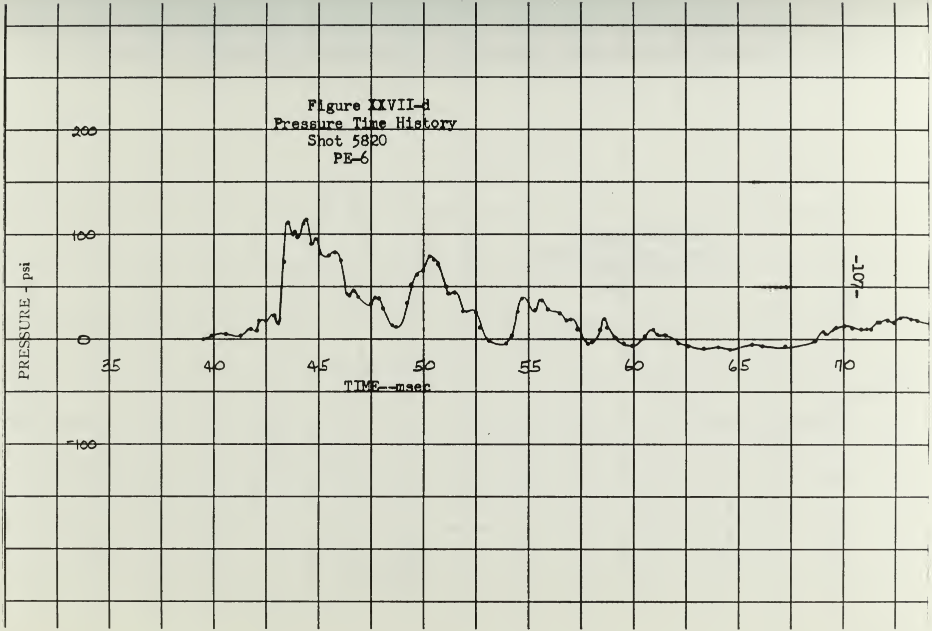


Figure XXVII-d
Pressure Time History
Shot 5820
PE-6

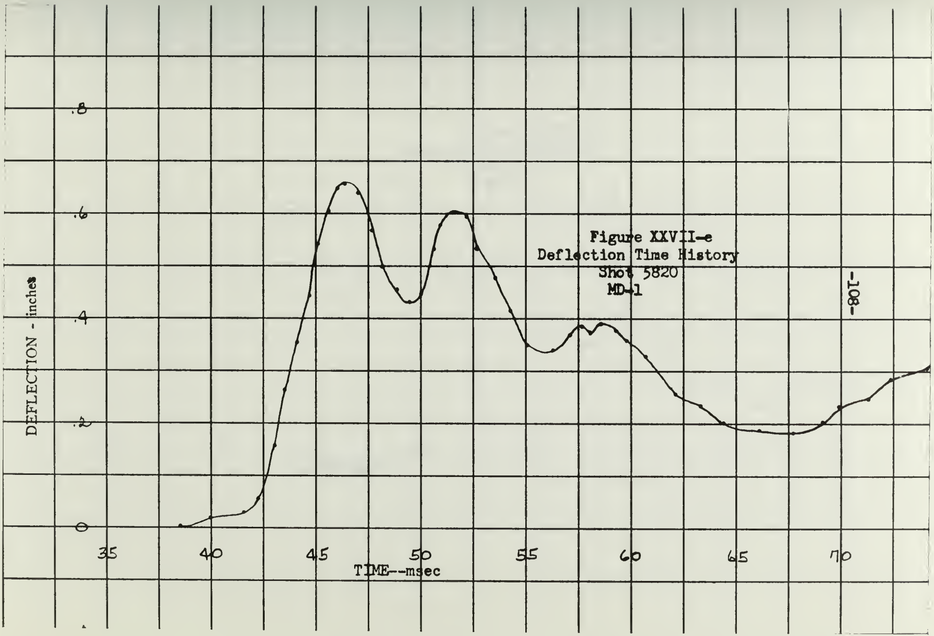


Figure XXVII-e
Deflection Time History
Shot 5820
MD-1

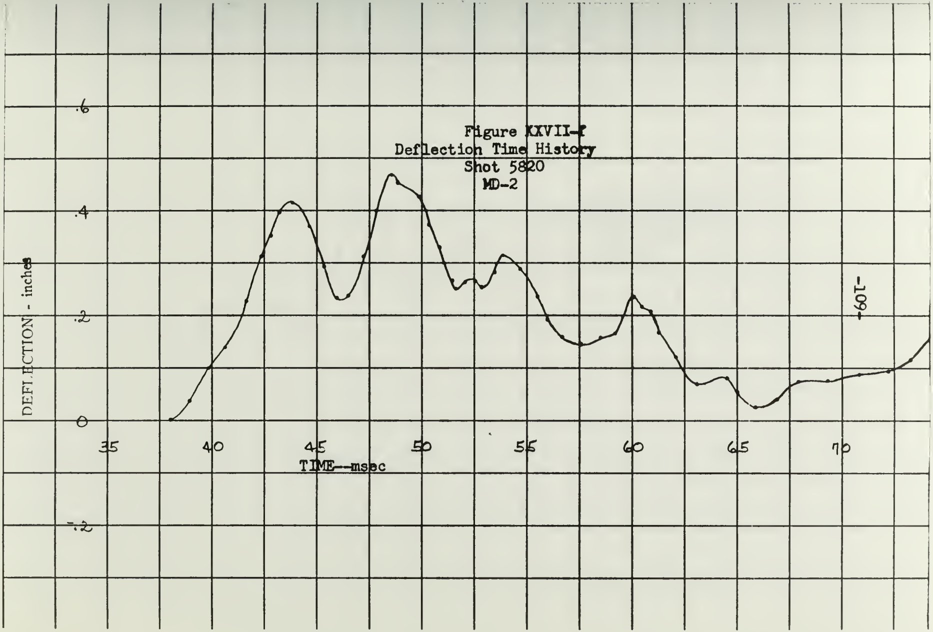


Figure XXVII-f
Deflection Time History
Shot 5820
MD-2

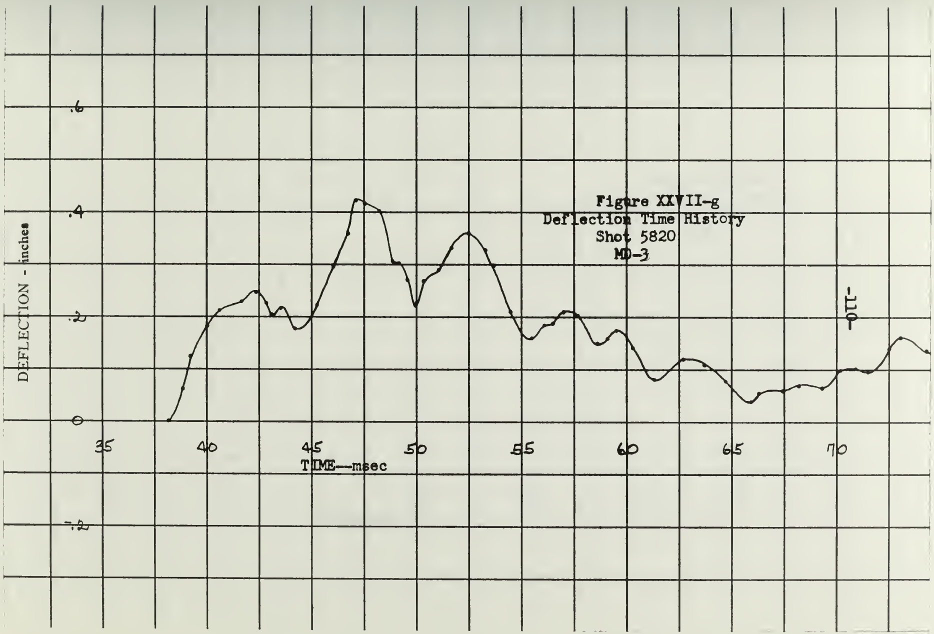


Figure XXVII-g
Deflection Time History
Shot 5820
MD-3

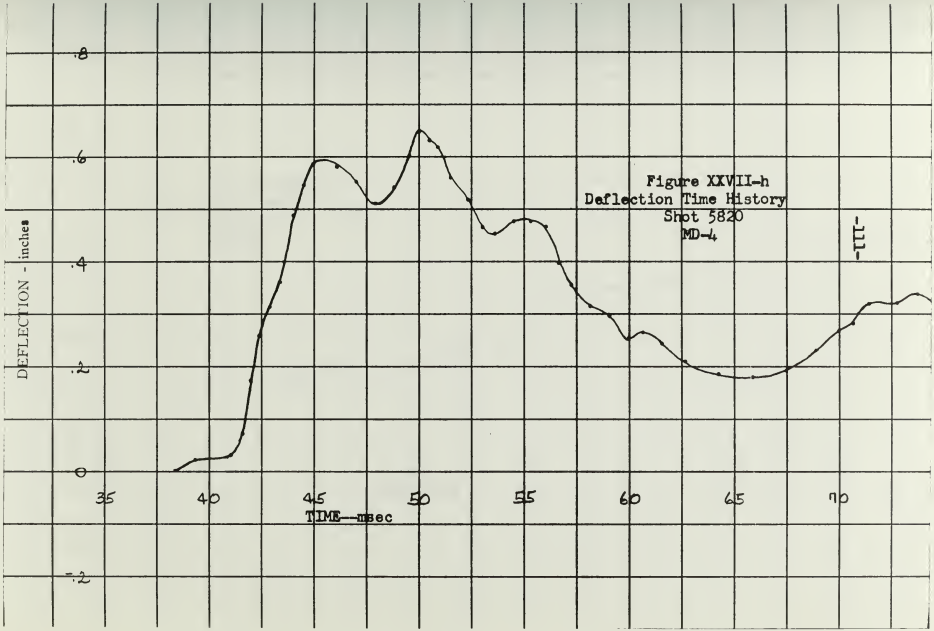


Figure XXVII-h
Deflection Time History
Shot 5820
MD-4

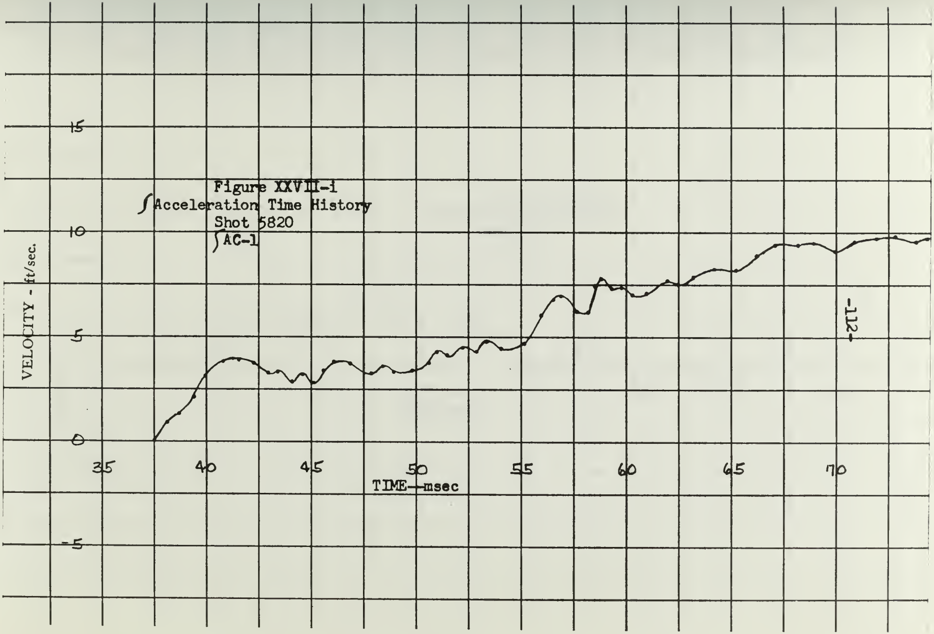


Figure XXVIII-1
∫Acceleration Time History
Shot 5820
∫AC-1

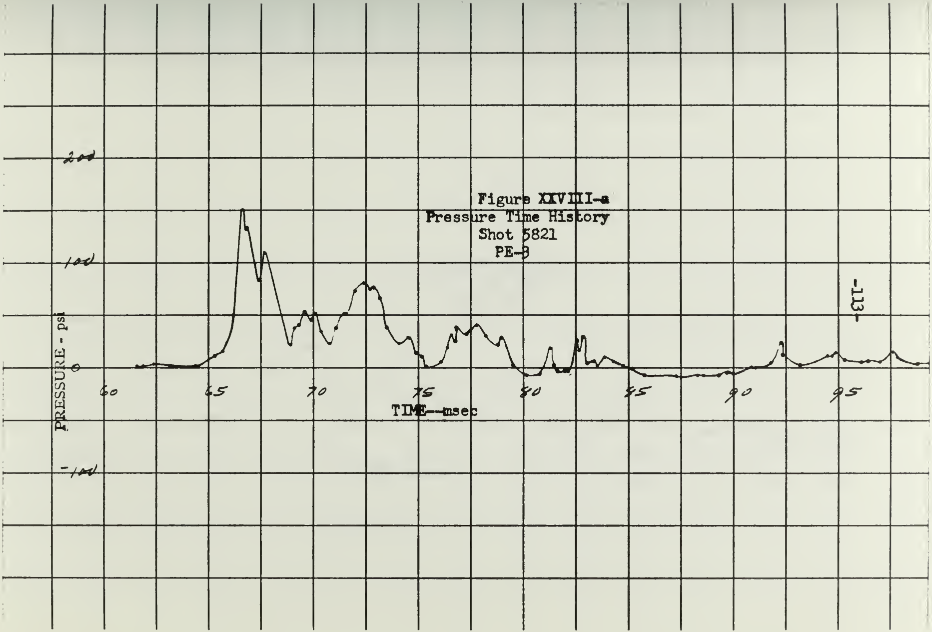


Figure XXVIII-a
Pressure Time History
Shot 5821
PE-3

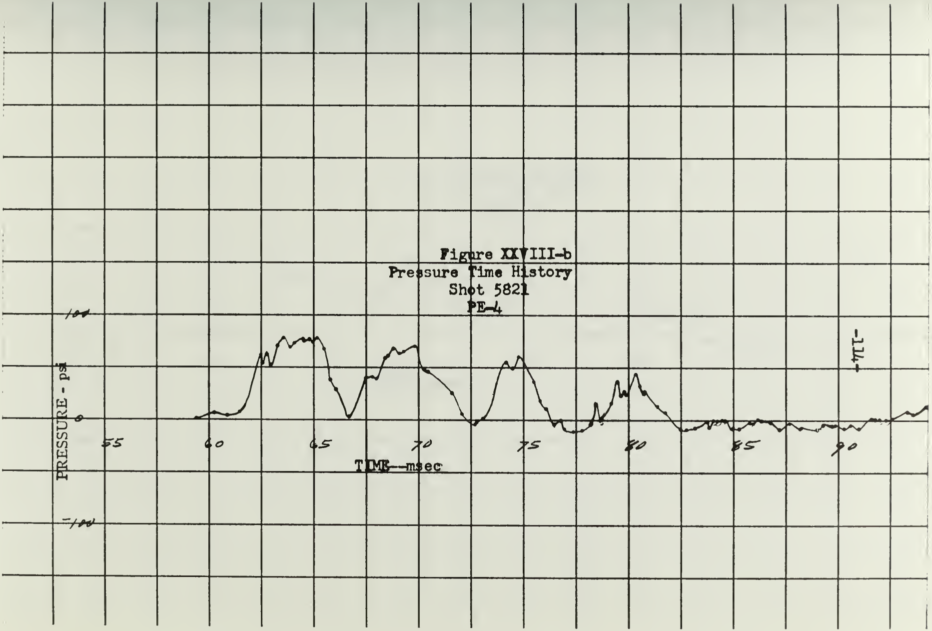


Figure XXVIII-b
Pressure Time History
Shot 5821
PE-4

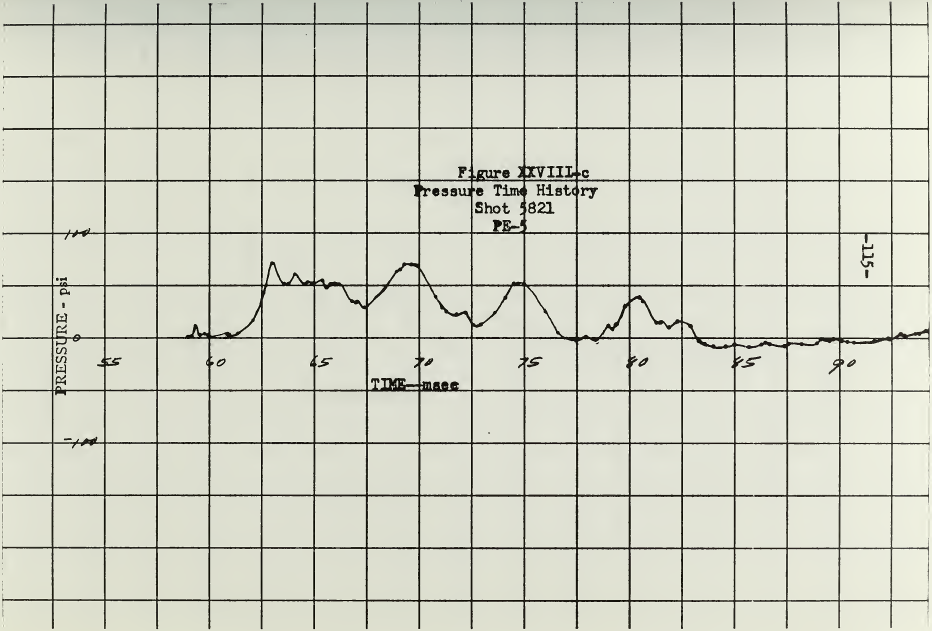


Figure XXVIII-c
Pressure Time History
Shot 5821
PE-5

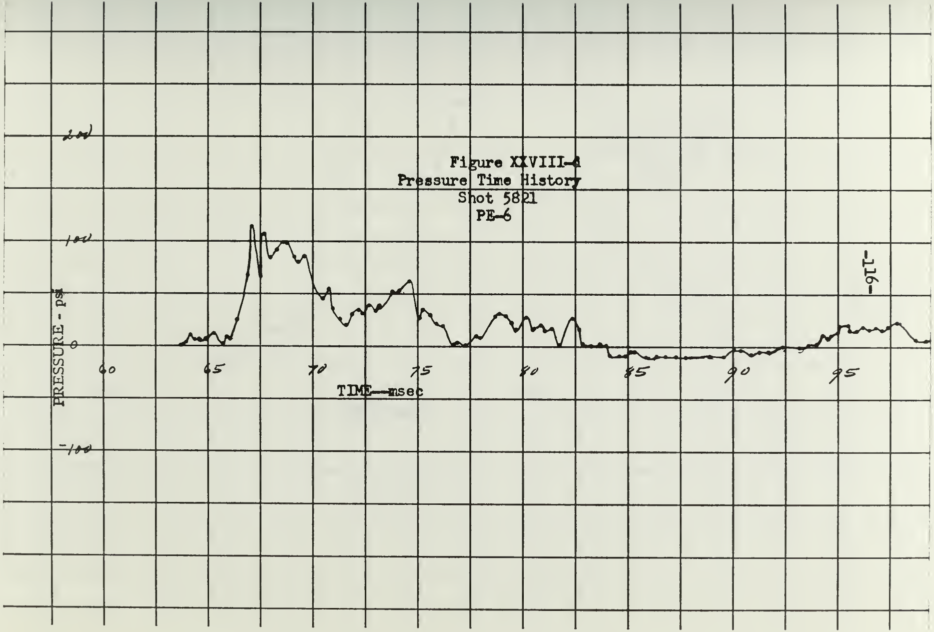


Figure XXVIII-4
Pressure Time History
Shot 5821
PE-6

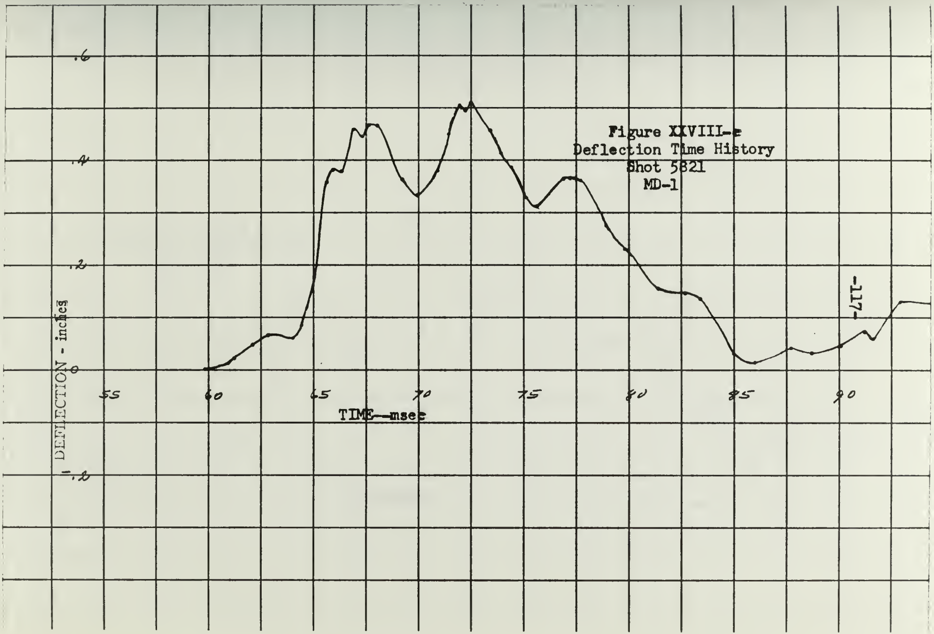


Figure XXVIII-e
Deflection Time History
Shot 5821
MD-1

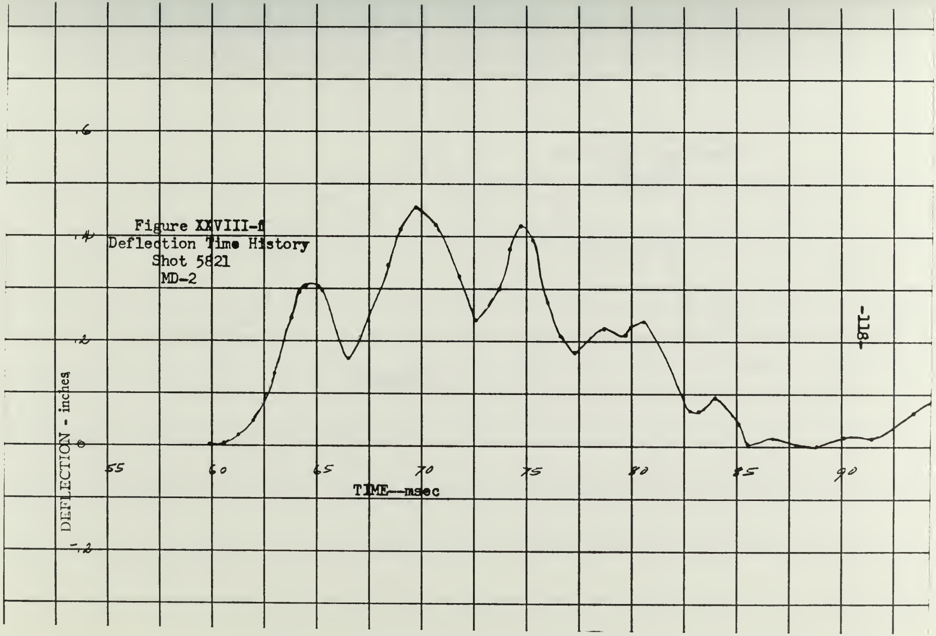


Figure XXVIII-f
Deflection Time History
Shot 5821
MD-2

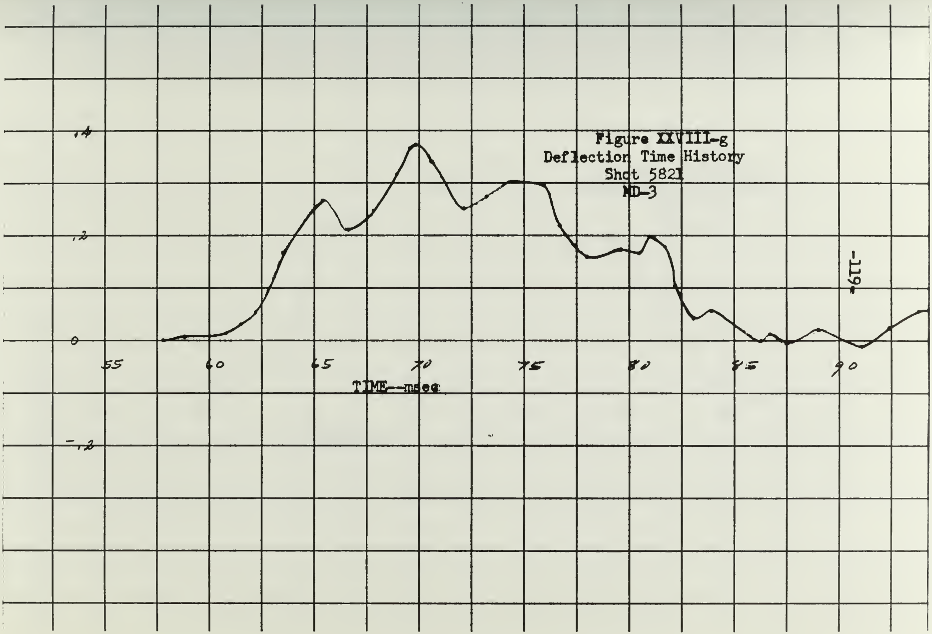


Figure XXVIII-g
Deflection Time History
Shot 5821
MD-3

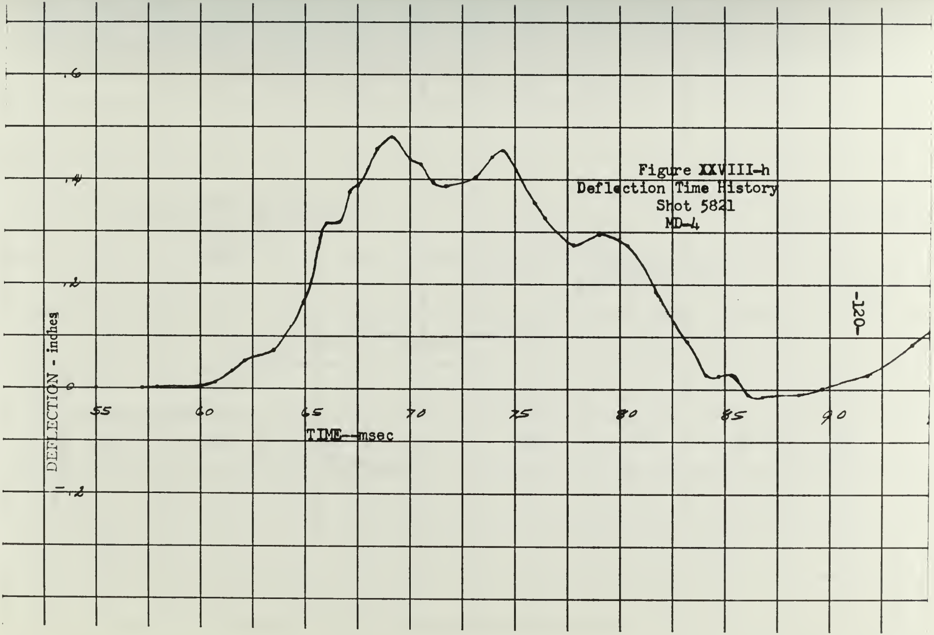


Figure XXVIII-h
Deflection Time History
Shot 5821
MD-4

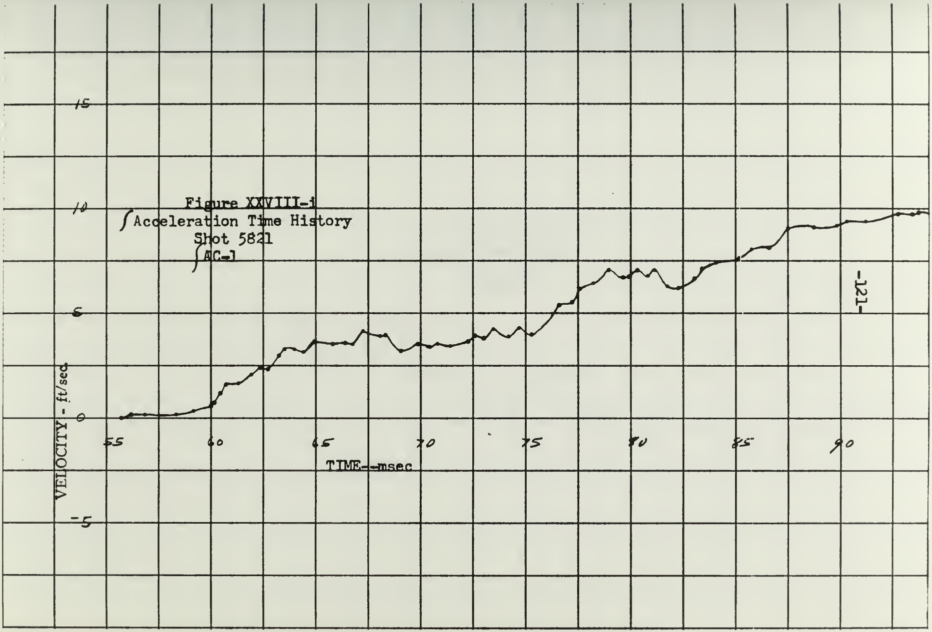


Figure XXVIII-1
∫Acceleration Time History
Shot 5821
∫AC-1

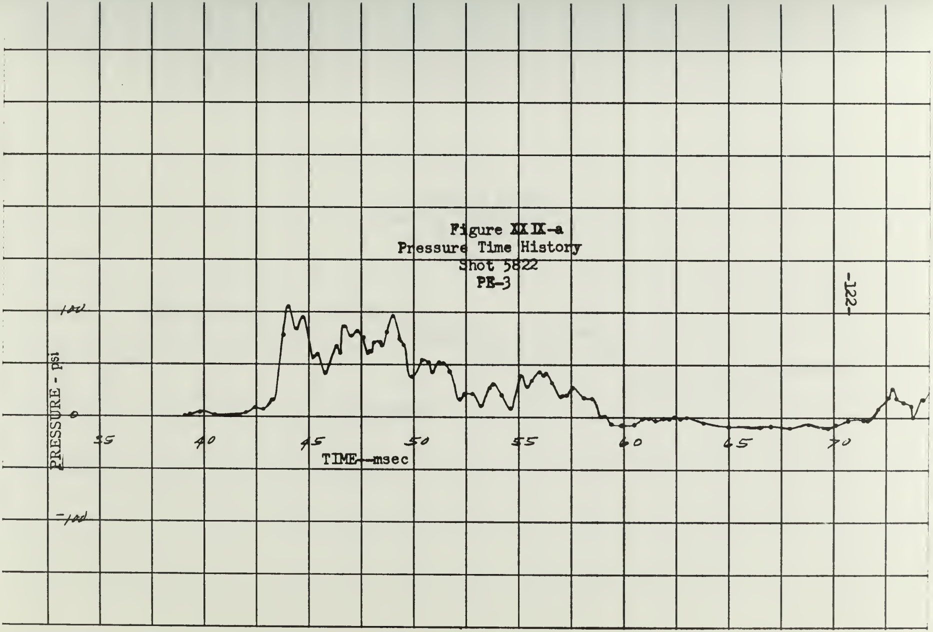


Figure XXIX-a
Pressure Time History
Shot 5822
PE-3

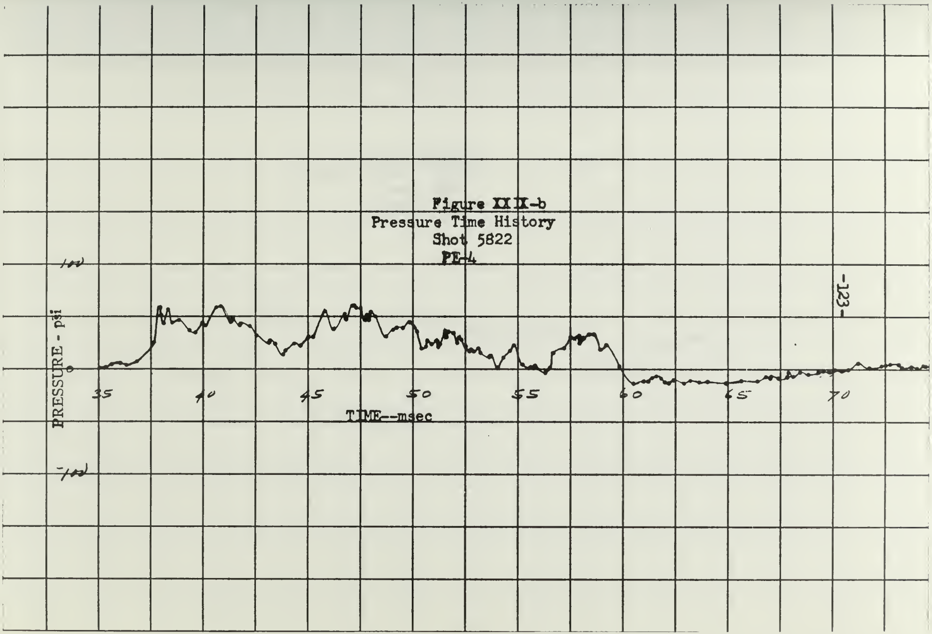


Figure XIX-b
Pressure Time History
Shot 5822
PE-4
PRESSURE - psi
100
0
-100
35
40
45
50
55
60
65
70
TIME--msec

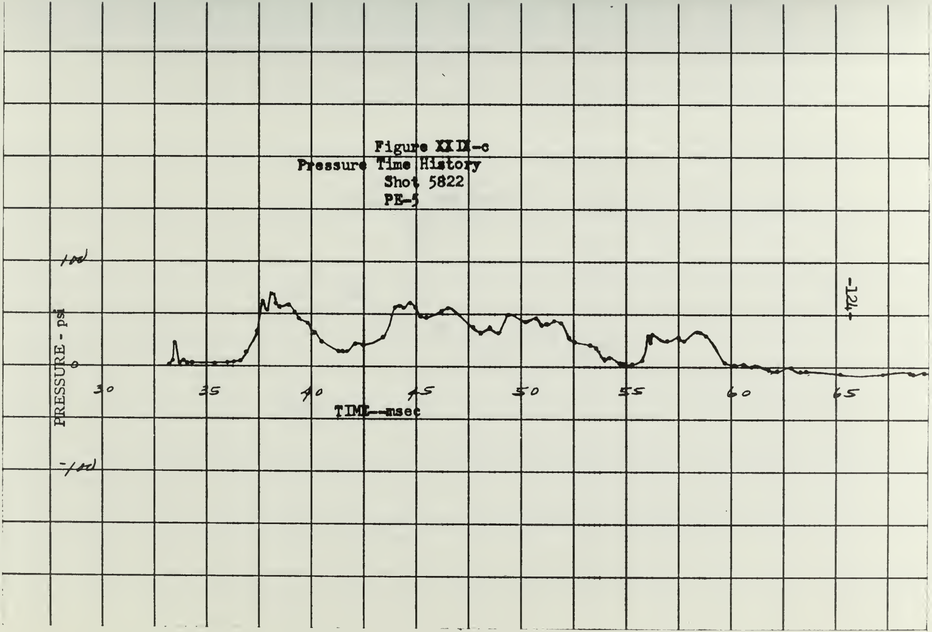


Figure XXIX-c
Pressure Time History
Shot 5822
PE-5

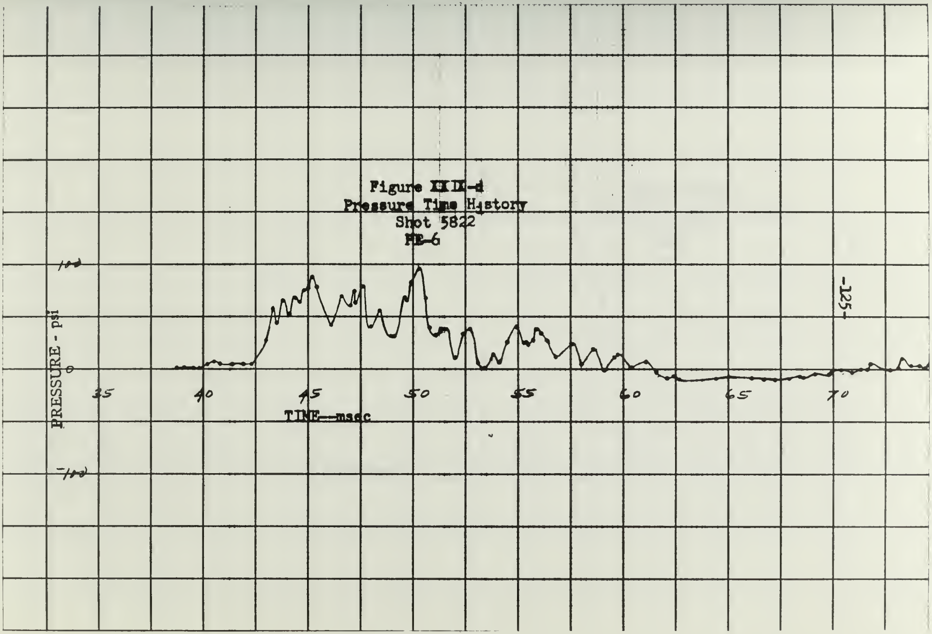


Figure XXIX-d
Pressure Time History
Shot 5822
FE-6

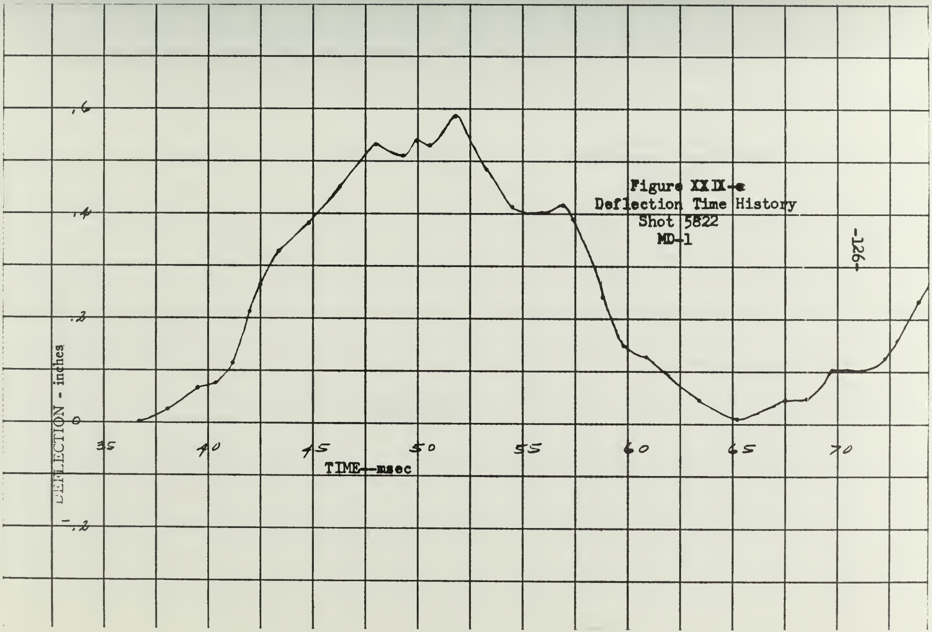


Figure XXIX-e
Deflection Time History
Shot 5822
MD-1

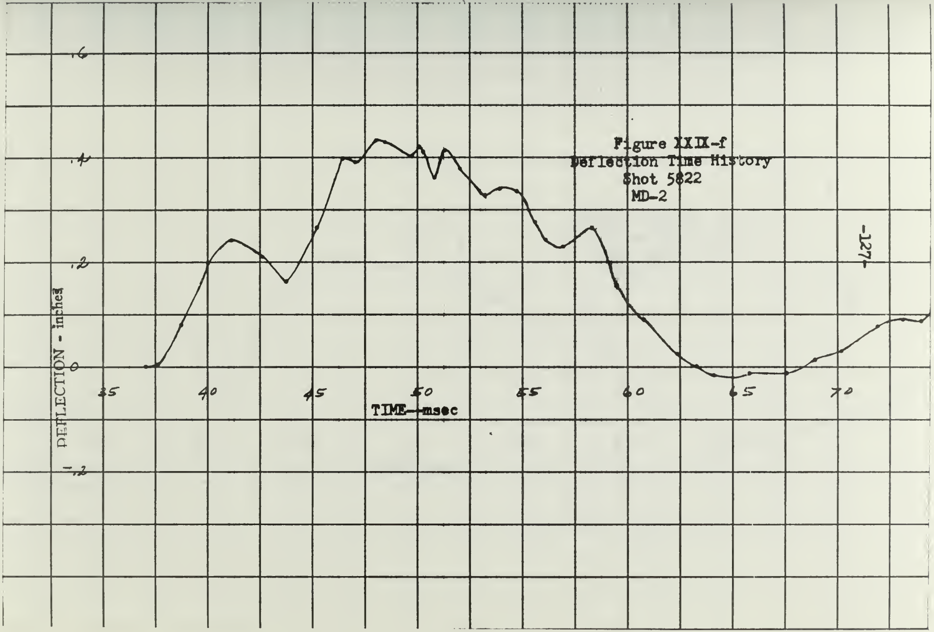


Figure XXIX-f
Deflection Time History
Shot 5822
MD-2

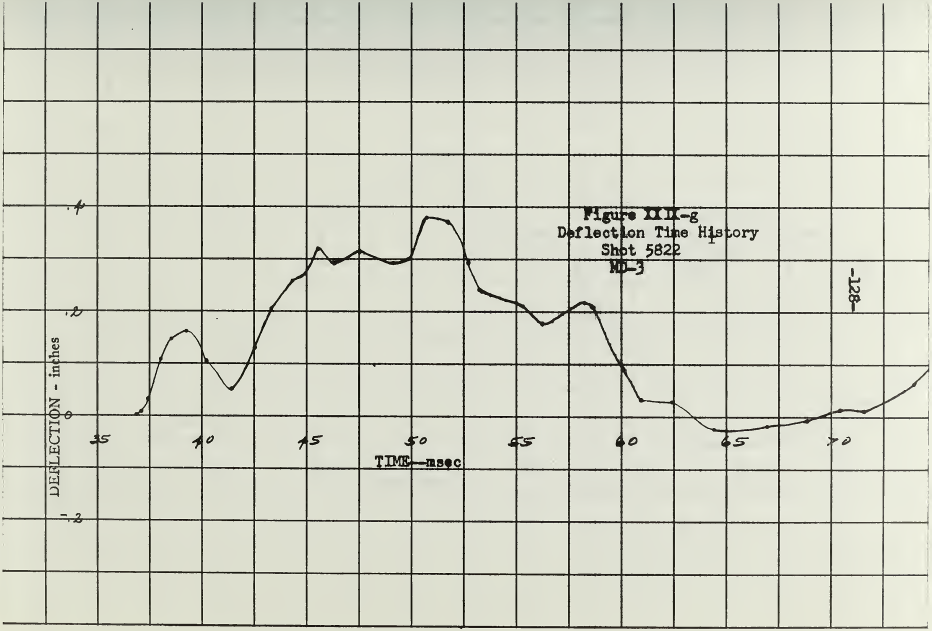


Figure XXII-g
Deflection Time History
Shot 5822
MD-3

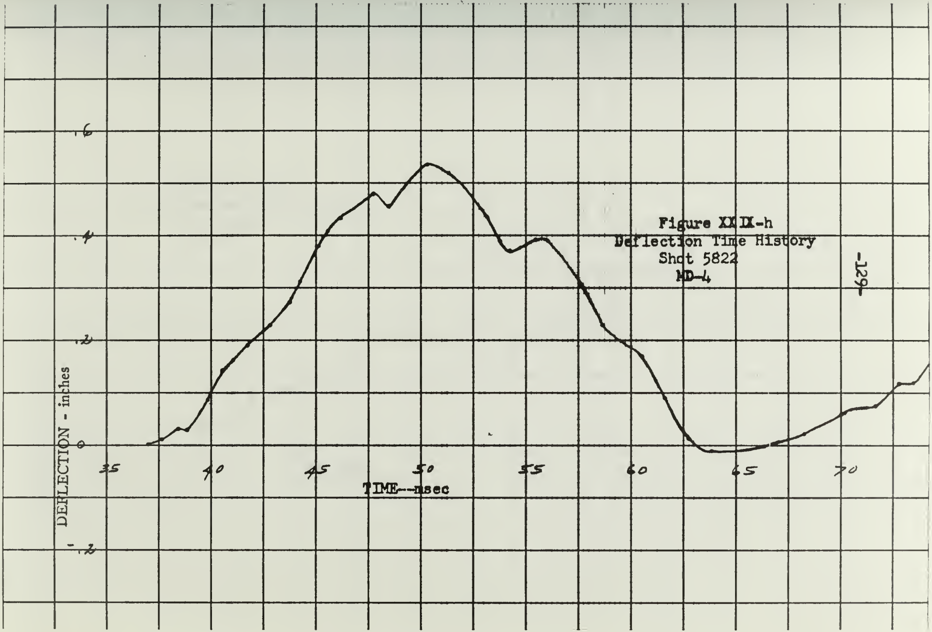


Figure XXIX-h
Deflection Time History
Shot 5822
MD-4

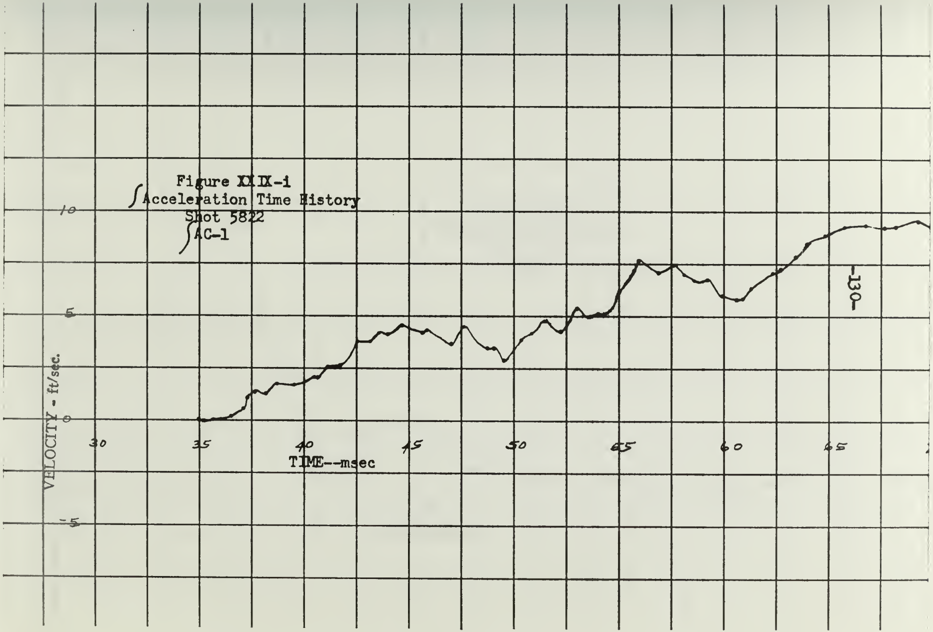


Figure XXIX-1
∫Acceleration Time History
Shot 5822
∫AC-1

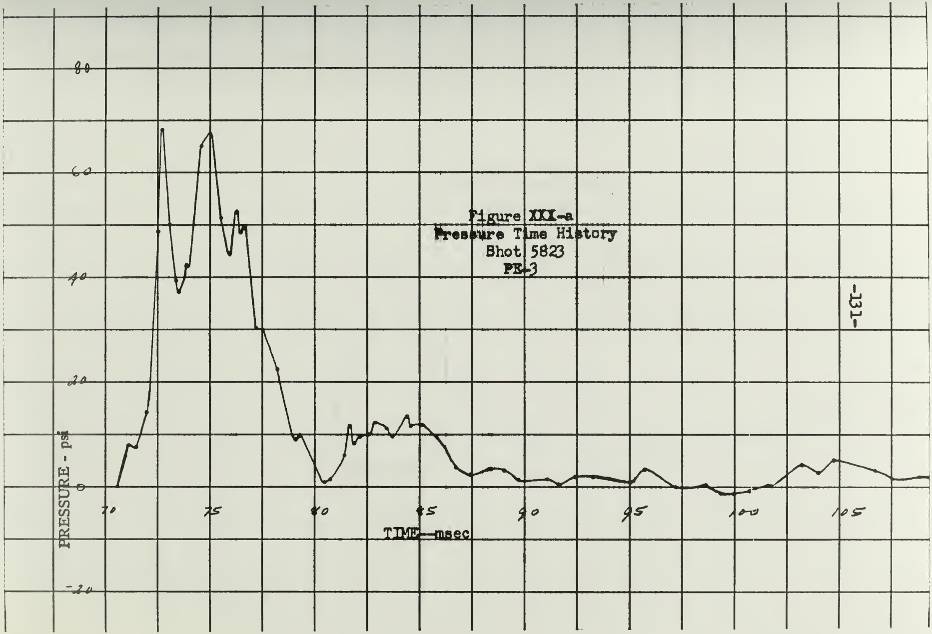


Figure XXX-a
Pressure Time History
Shot 5823
PE-3

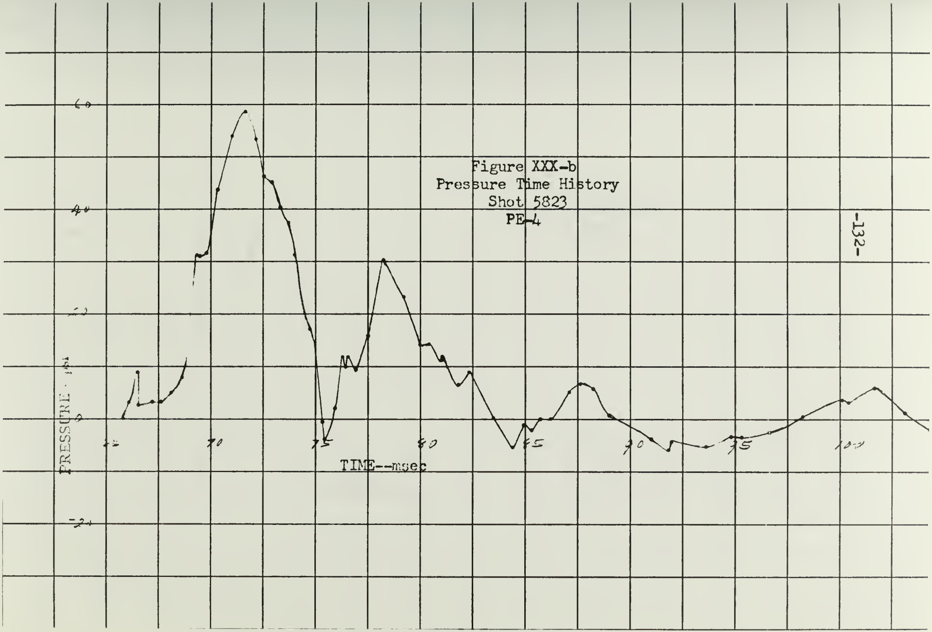


Figure XXX-b
Pressure Time History
Shot 5823
PE-4

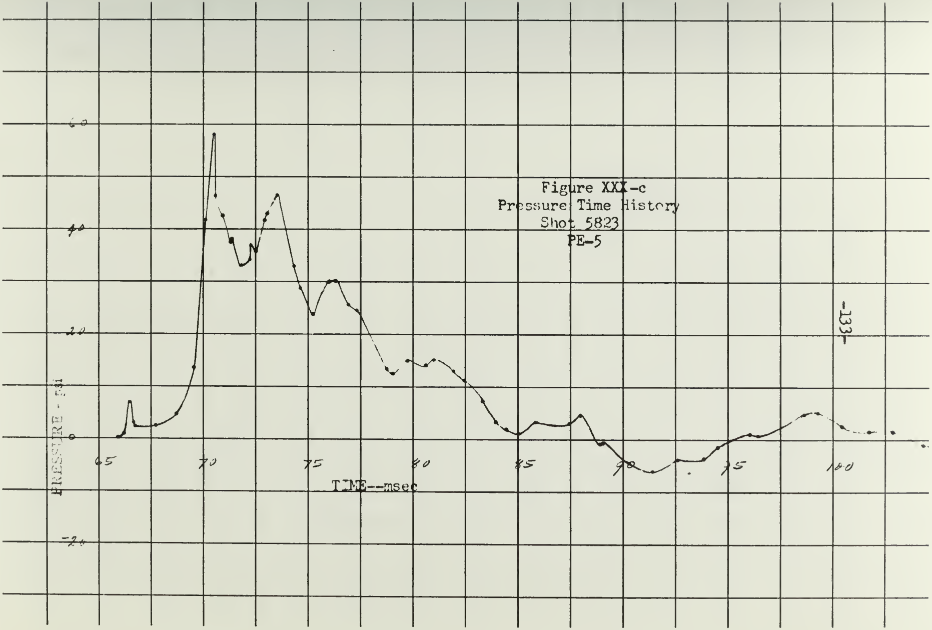


Figure XXI-c
Pressure Time History
Shot 5823
PE-5

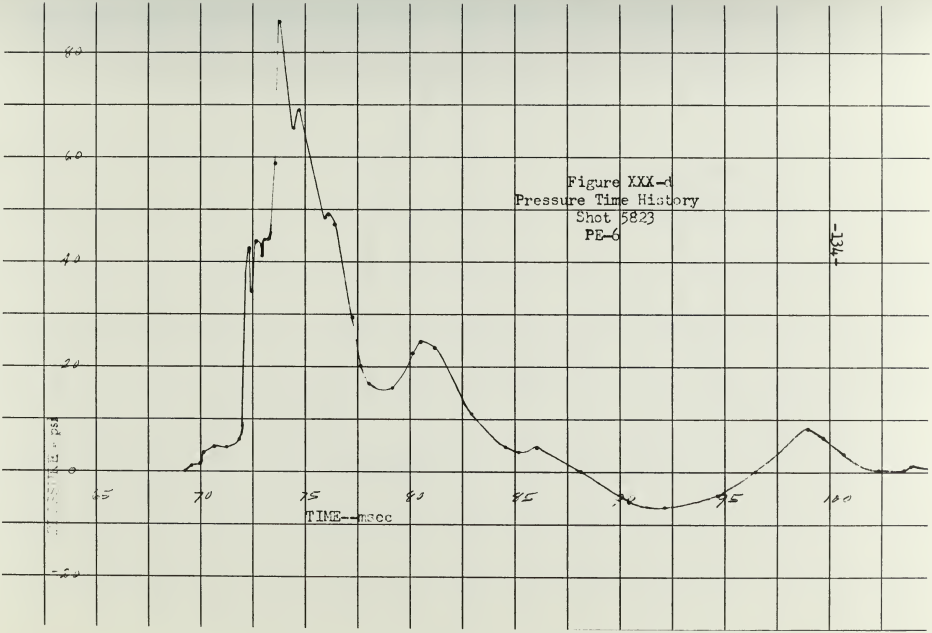


Figure XXX-d
Pressure Time History
Shot 5823
PE-6

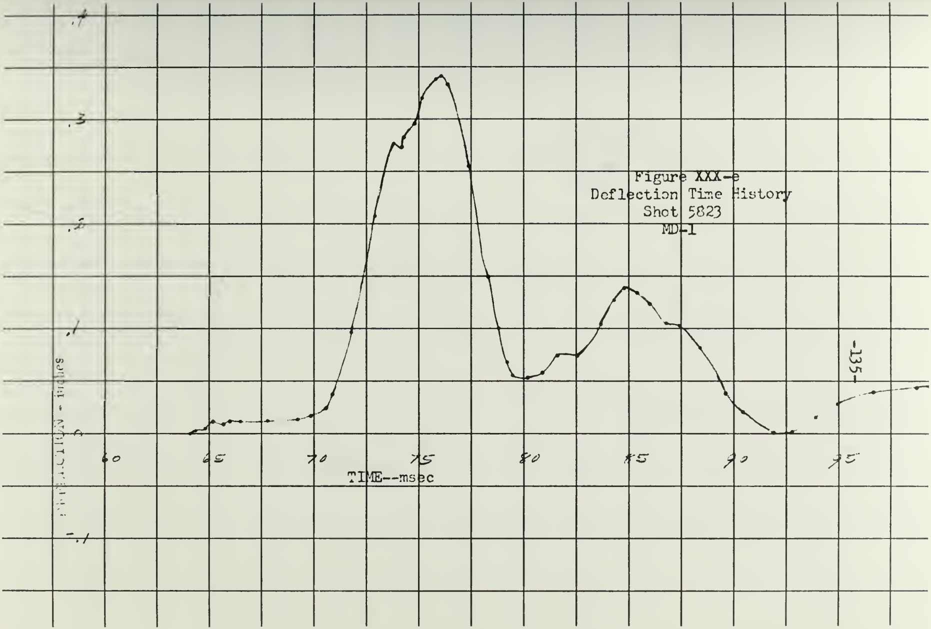


Figure XXX-e
Deflection Time History
Shot 5823
MD-1

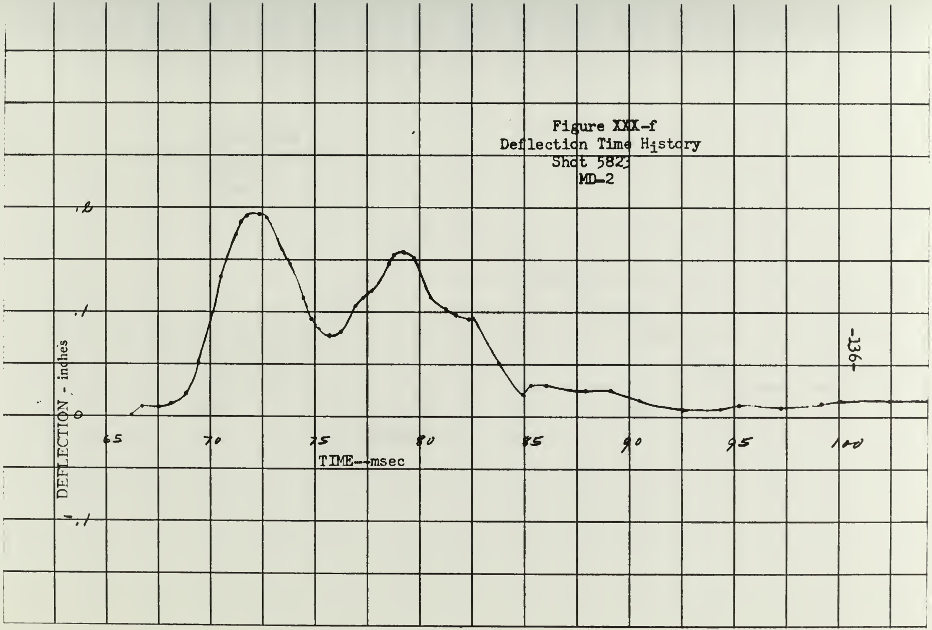
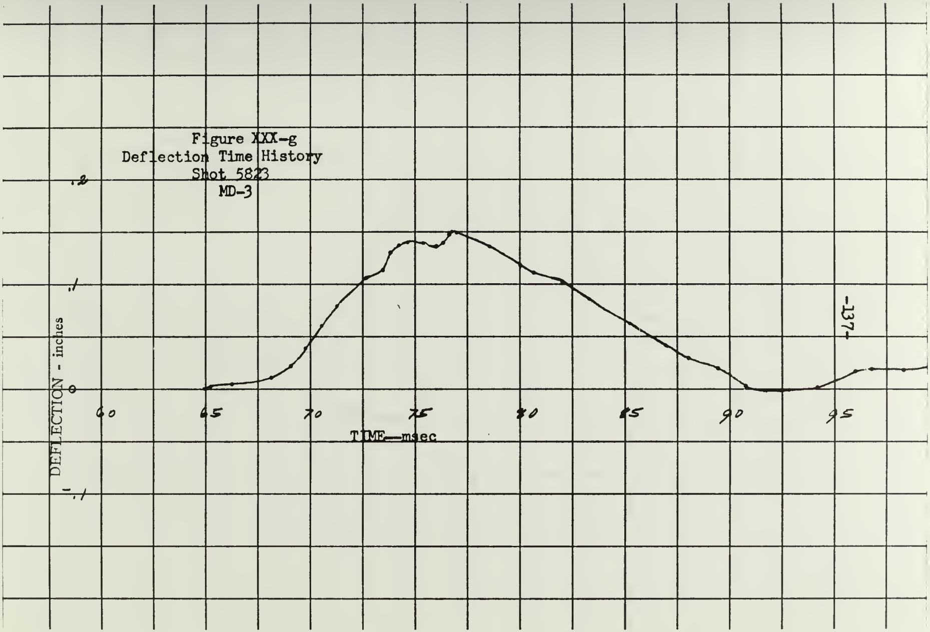


Figure XXX-f
Deflection Time History
Shot 5823
MD-2

Figure XXX-g
Deflection Time History
Shot 5823
MD-3



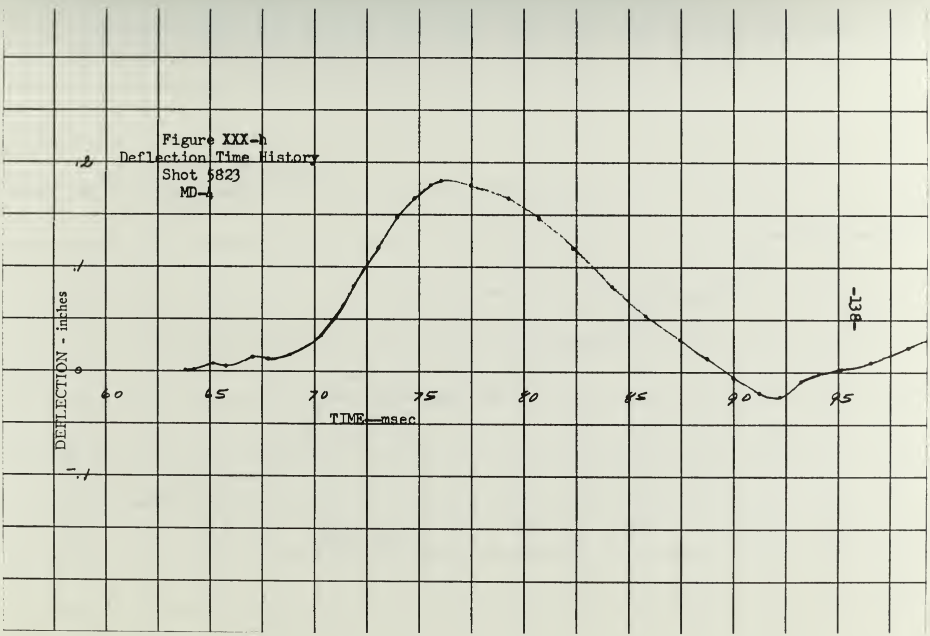


Figure XXX-h
Deflection Time History
Shot 5823
MD-4

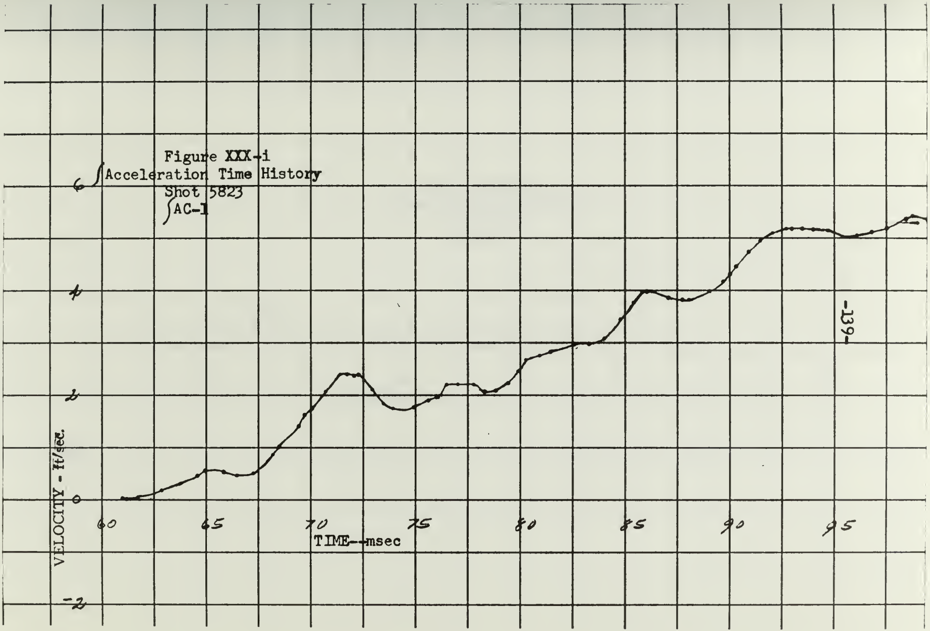


Figure XXX-i
∫Acceleration Time History
Shot 5823
∫AC-1

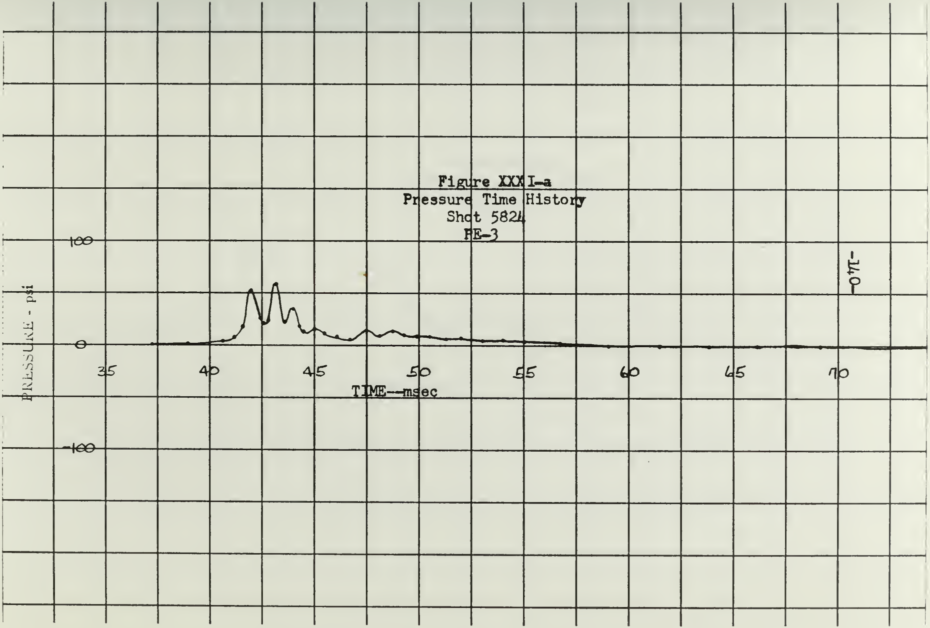


Figure XXXI-a
Pressure Time History
Shot 5824
PE-3

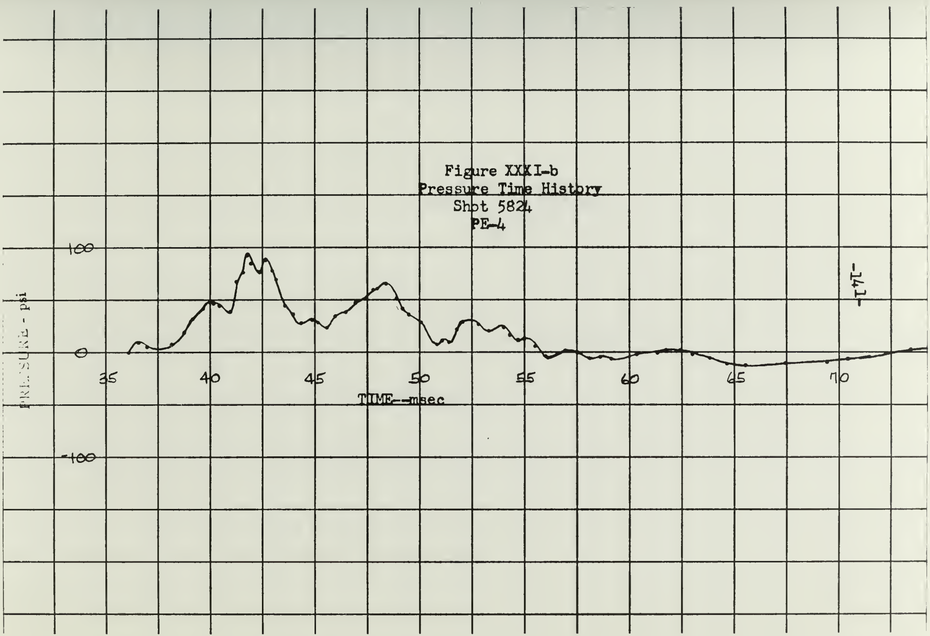


Figure XXXI-b
Pressure Time History
Shot 5824
PE-4

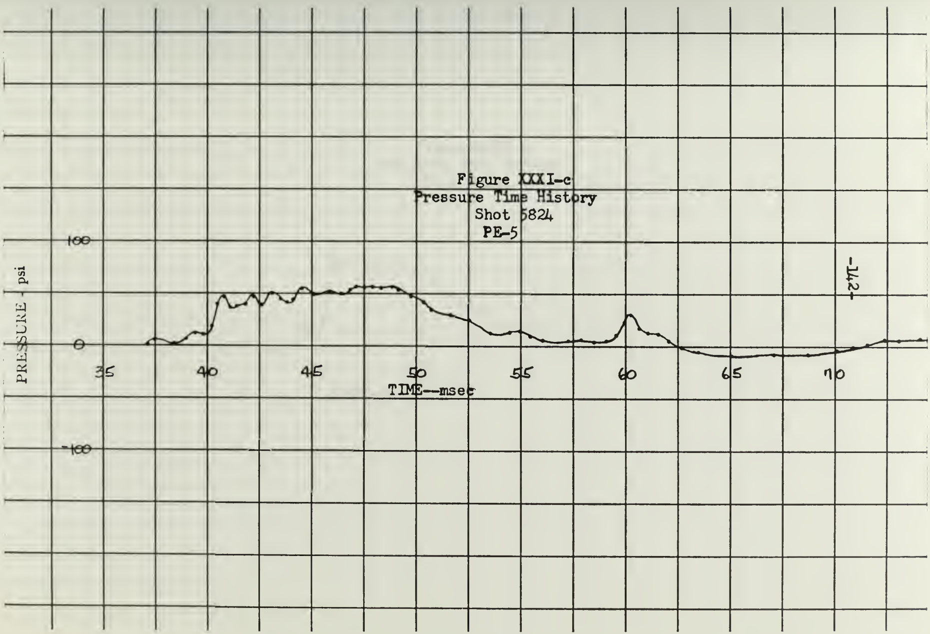


Figure XXXI-c
Pressure Time History
Shot 5824
PE-5

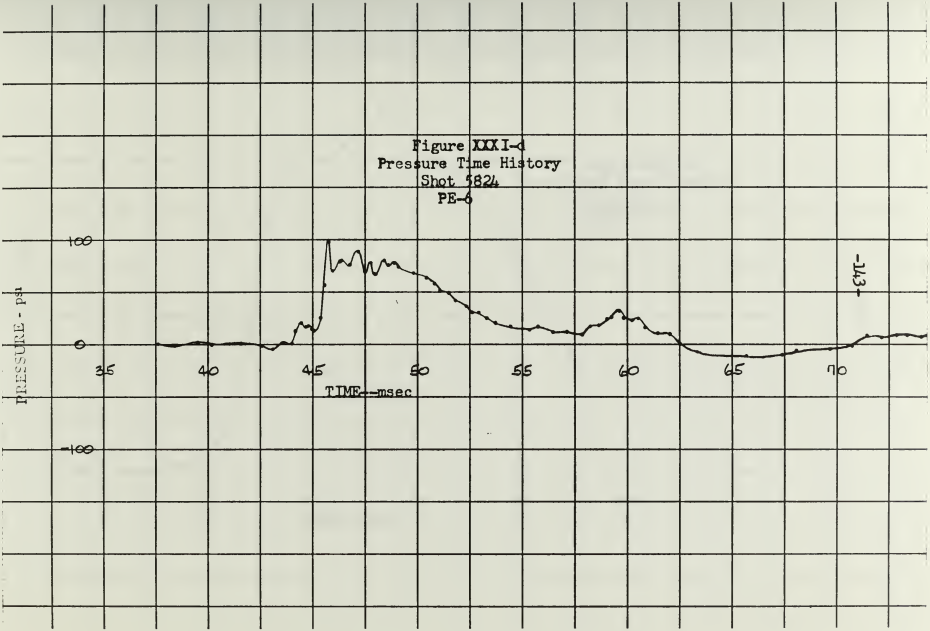


Figure XXXI-d
Pressure Time History
Shot 5824
PE-6

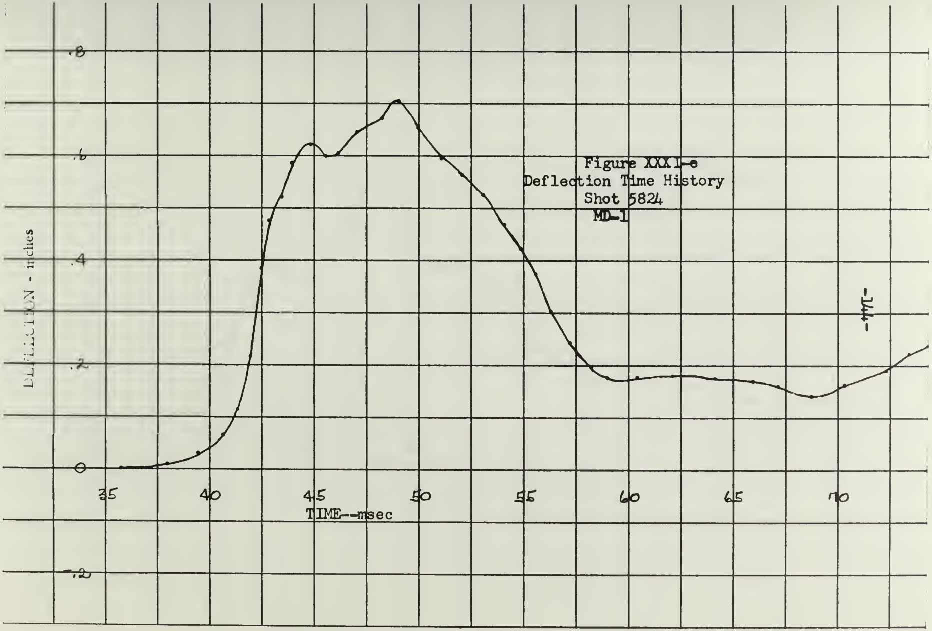


Figure XXXI-e
Deflection Time History
Shot 5824
MD-1

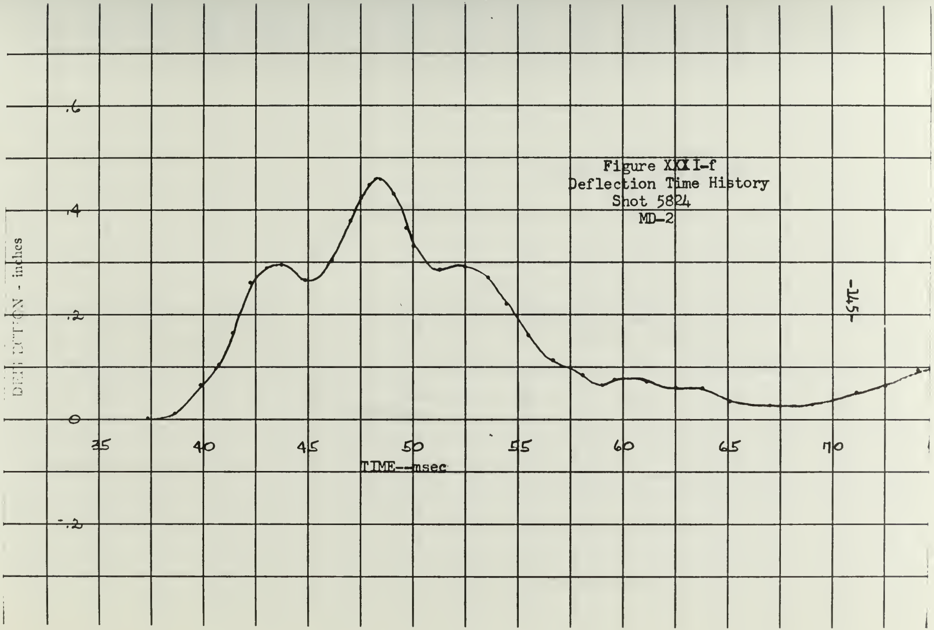


Figure XXXI-f
Deflection Time History
Shot 5824
MD-2

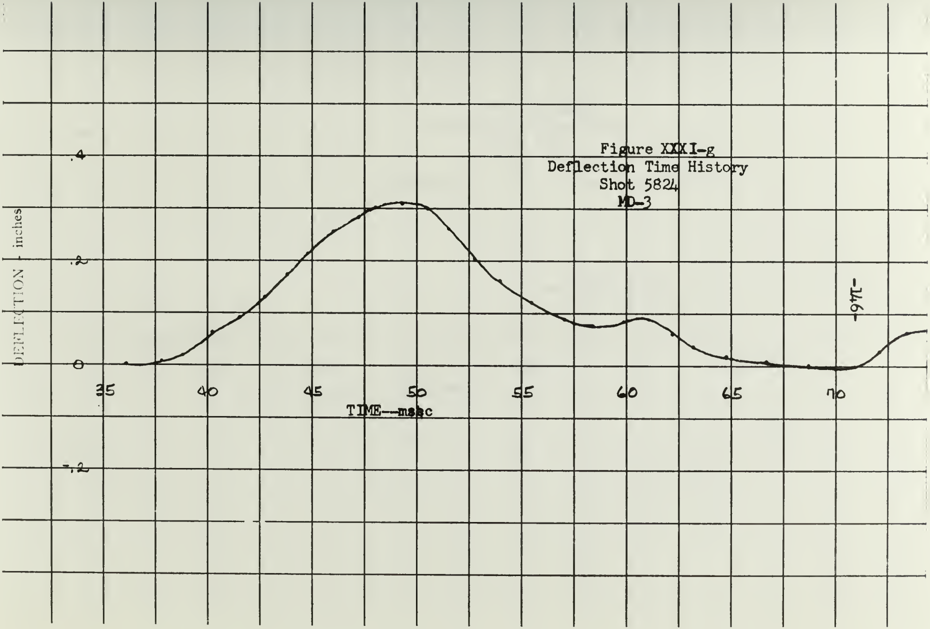


Figure XXXI-g
Deflection Time History
Shot 5824
MD-3

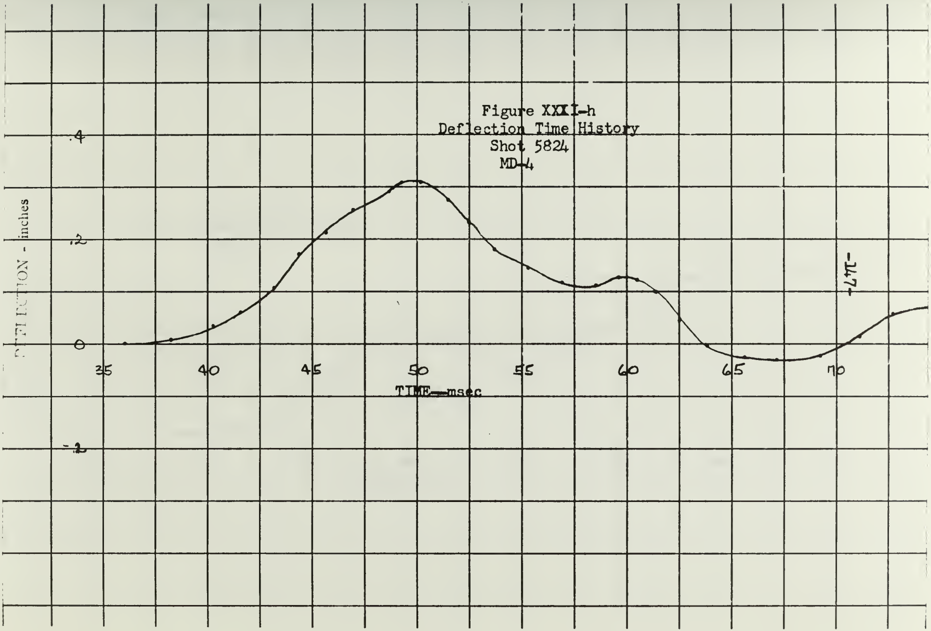


Figure XXXI-h
Deflection Time History
Shot 5824
MD-4

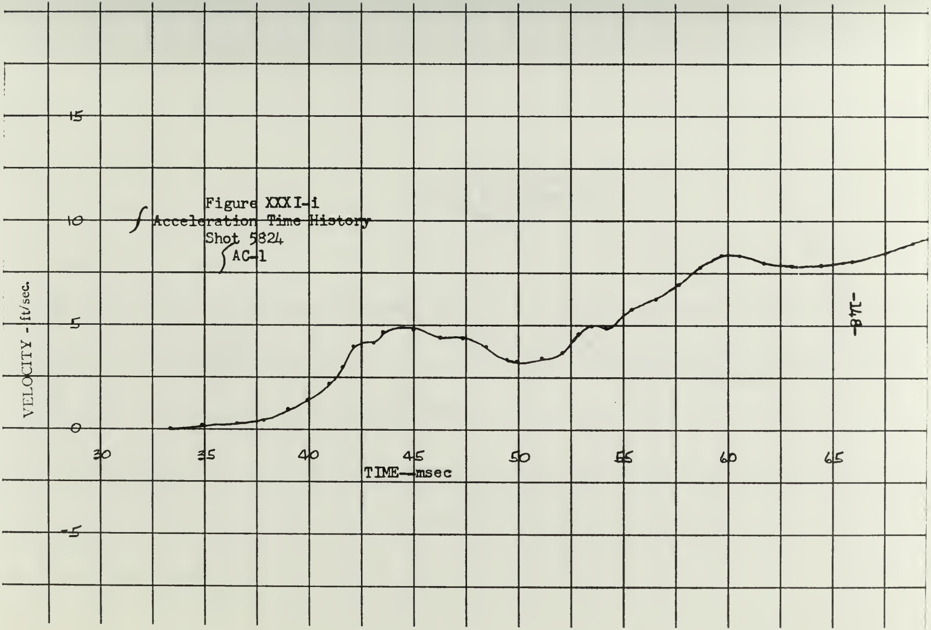


Figure XXXI-1
∫ Acceleration Time History
Shot 5824
∫ AC-1

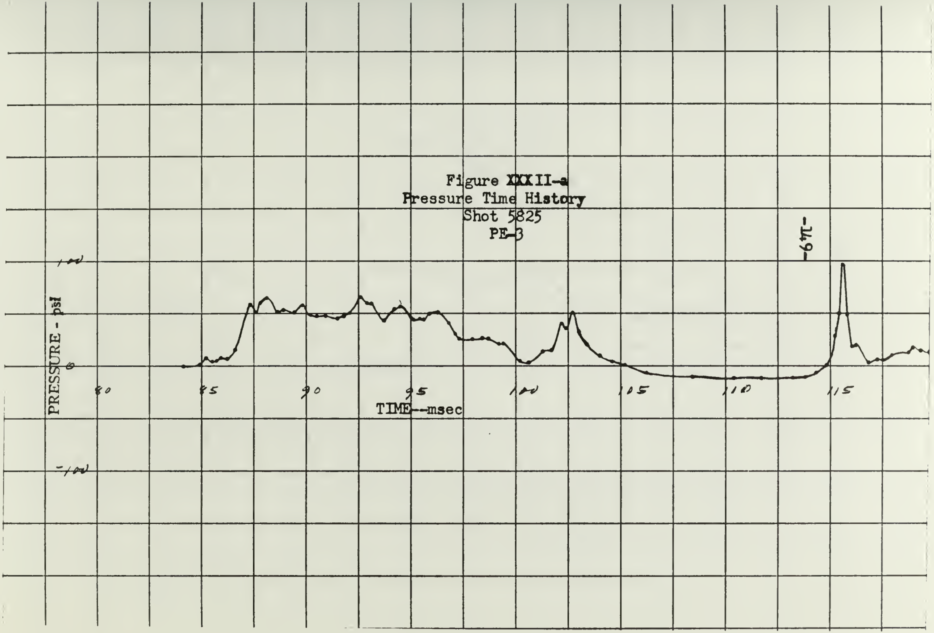


Figure XXXII-a
Pressure Time History
Shot 5825
PE-3

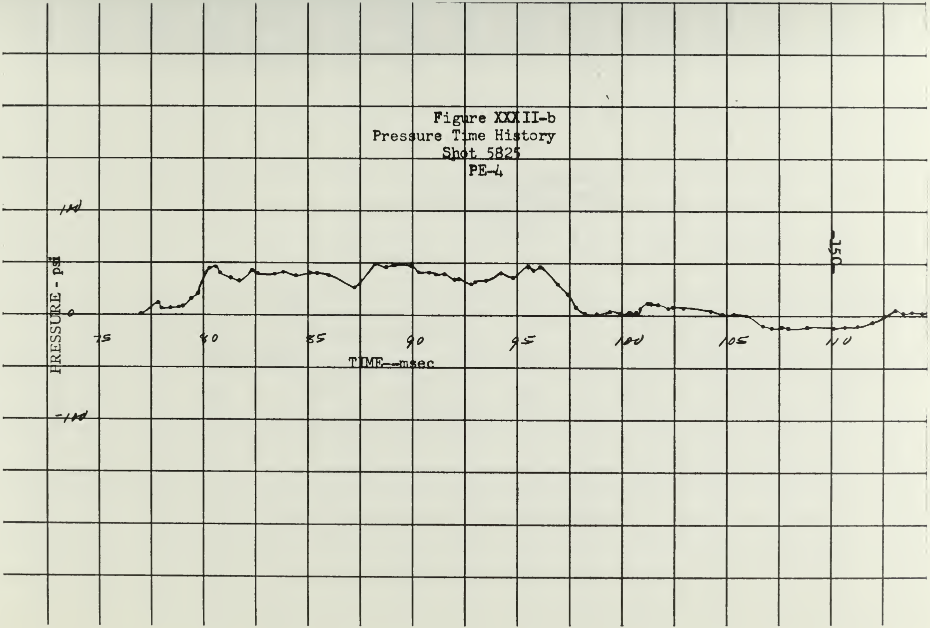


Figure XXXII-b
Pressure Time History
Shot 5825
PE-4

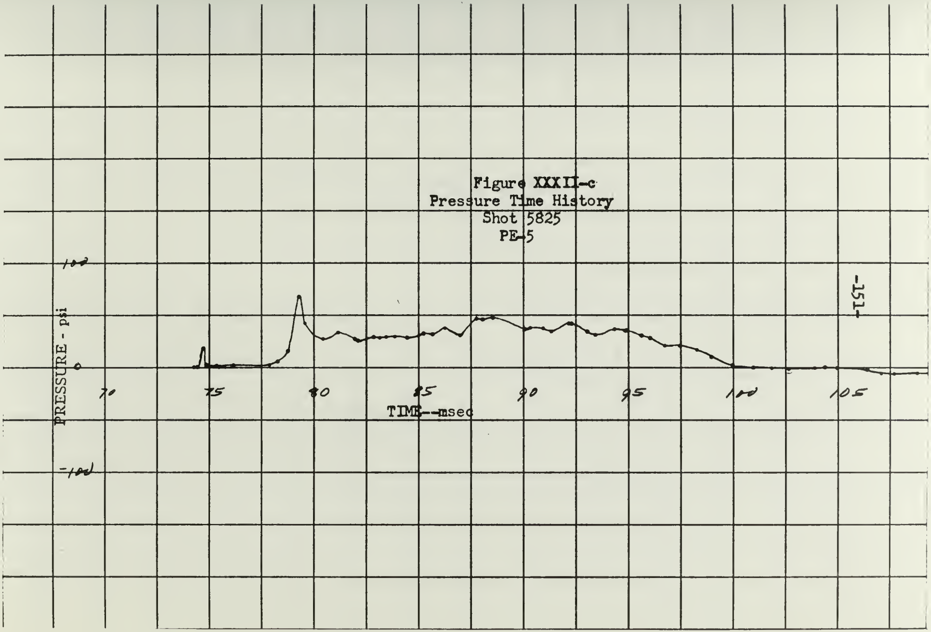


Figure XXXII-c
Pressure Time History
Shot 5825
PE-5

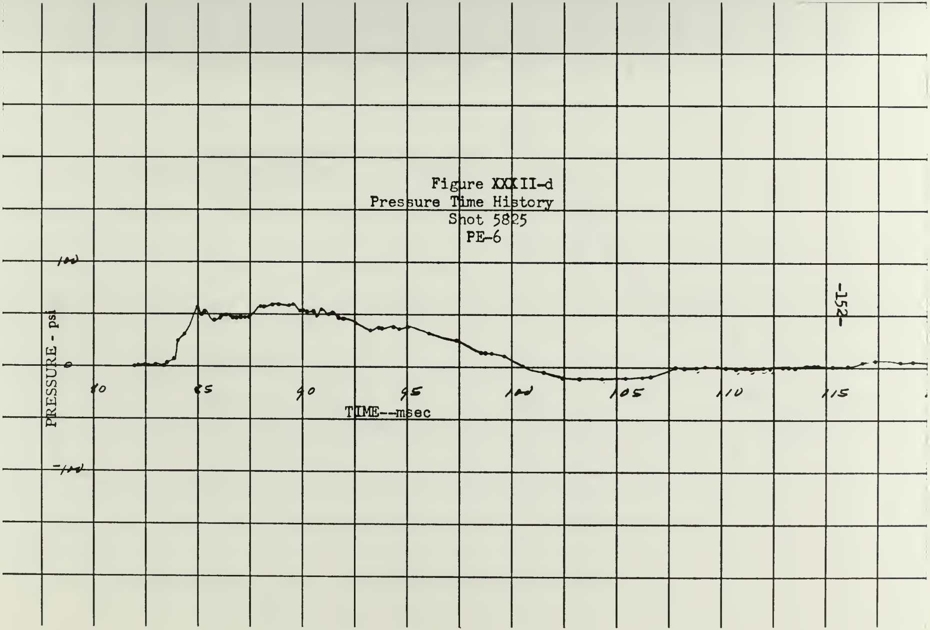


Figure XXXII-d
Pressure Time History
Shot 5825
PE-6

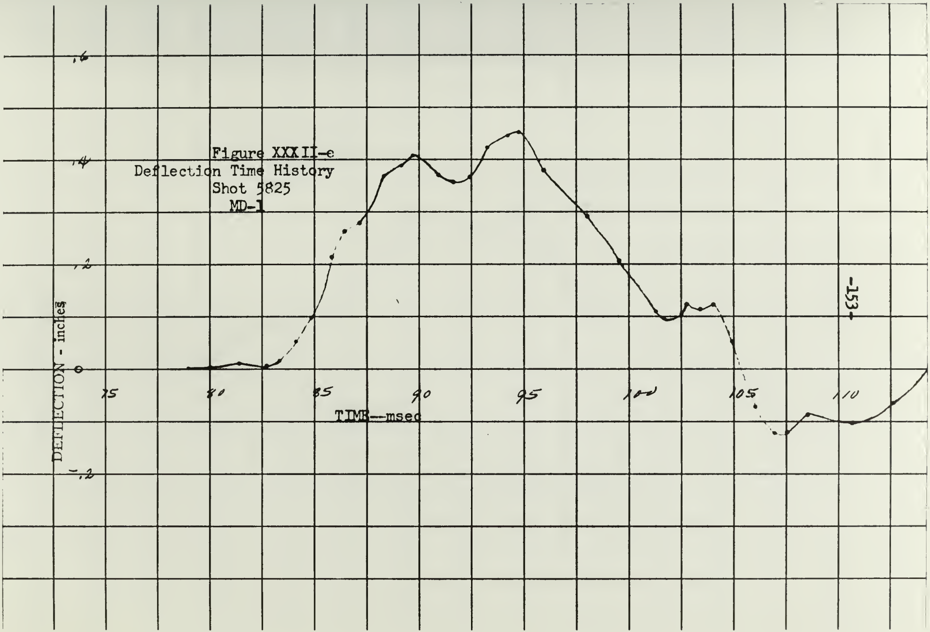


Figure XXXII-e
Deflection Time History
Shot 5825
MD-1

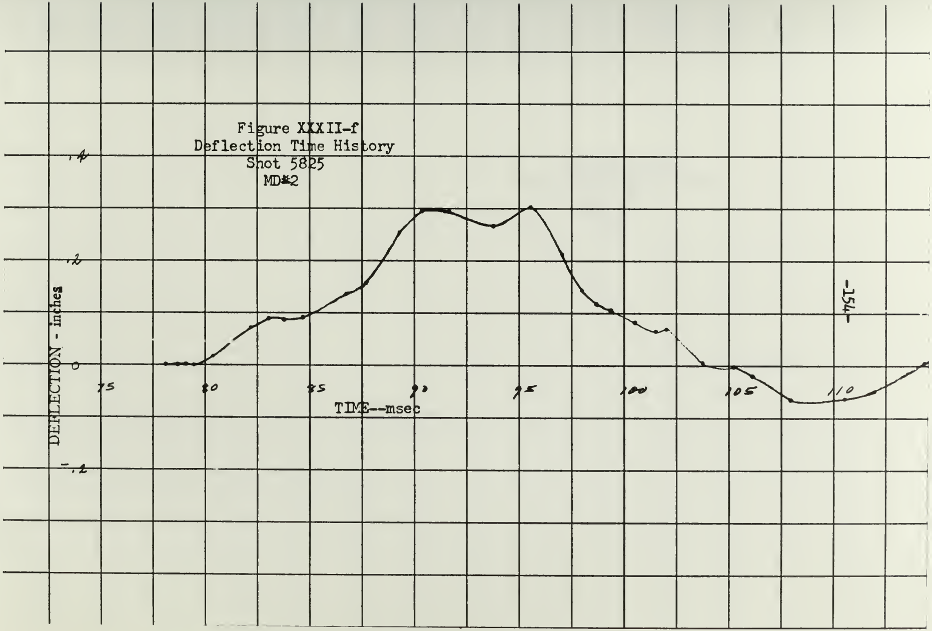


Figure XXXII-f
Deflection Time History
Shot 5825
MD#2

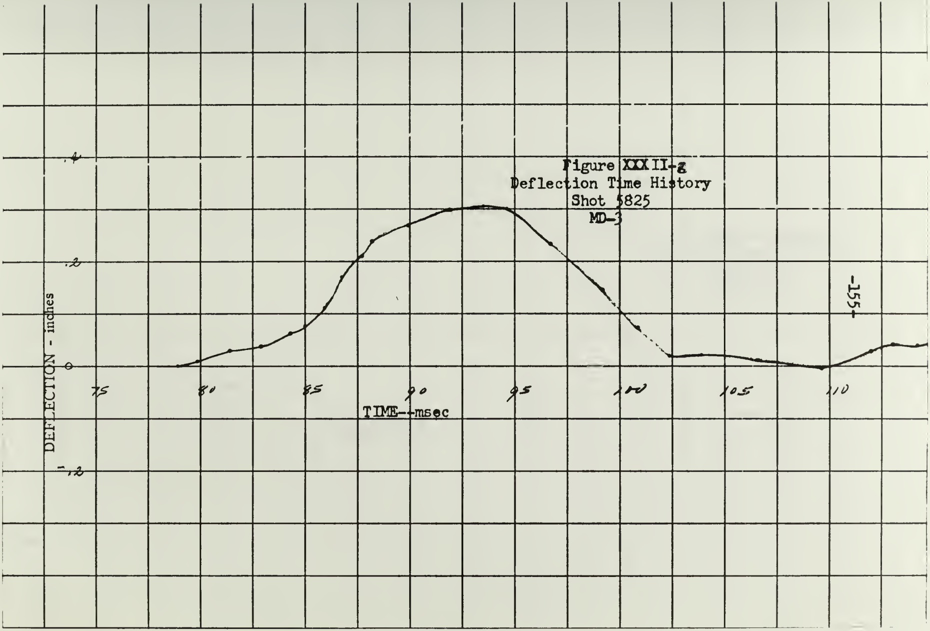


Figure XXXII-g
Deflection Time History
Shot 5825
MD-3
DEFLECTION - inches
TIME--msec
.4
.2
0
-.2
75
80
85
90
95
100
105
110

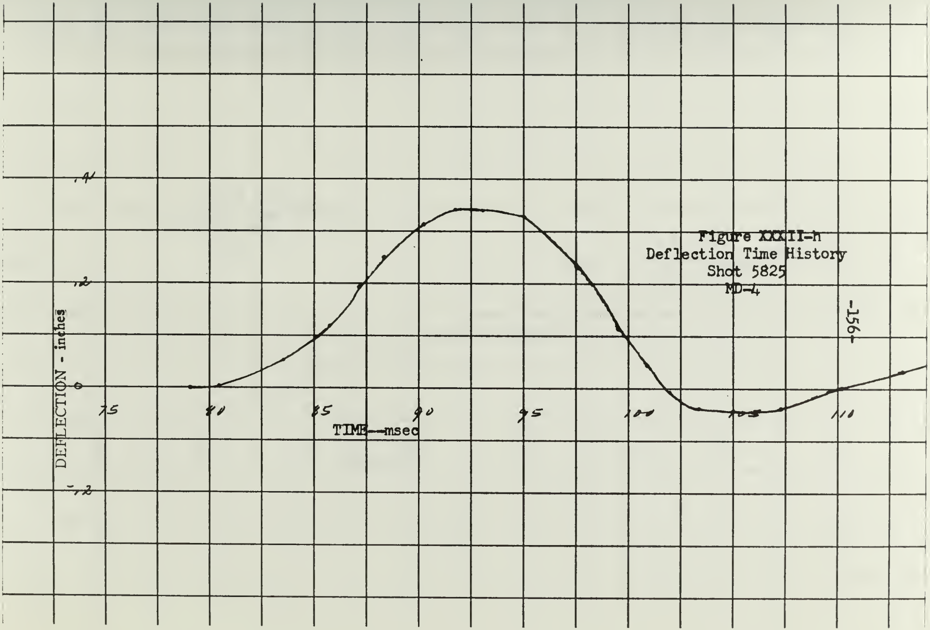


Figure XXXII-h
Deflection Time History
Shot 5825
MD-4

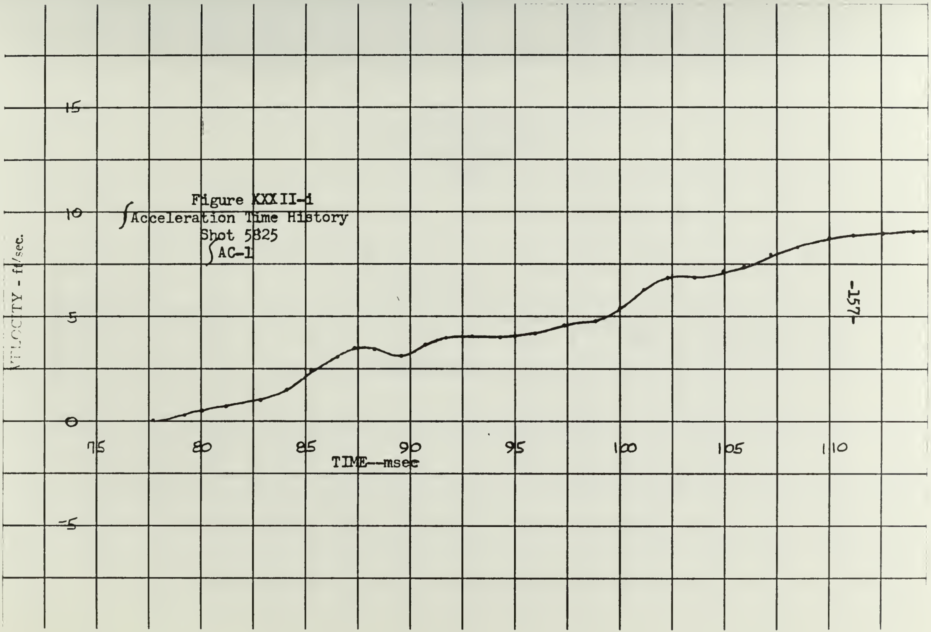


Figure XXXII-d
∫Acceleration Time History
Shot 5825
∫AC-1

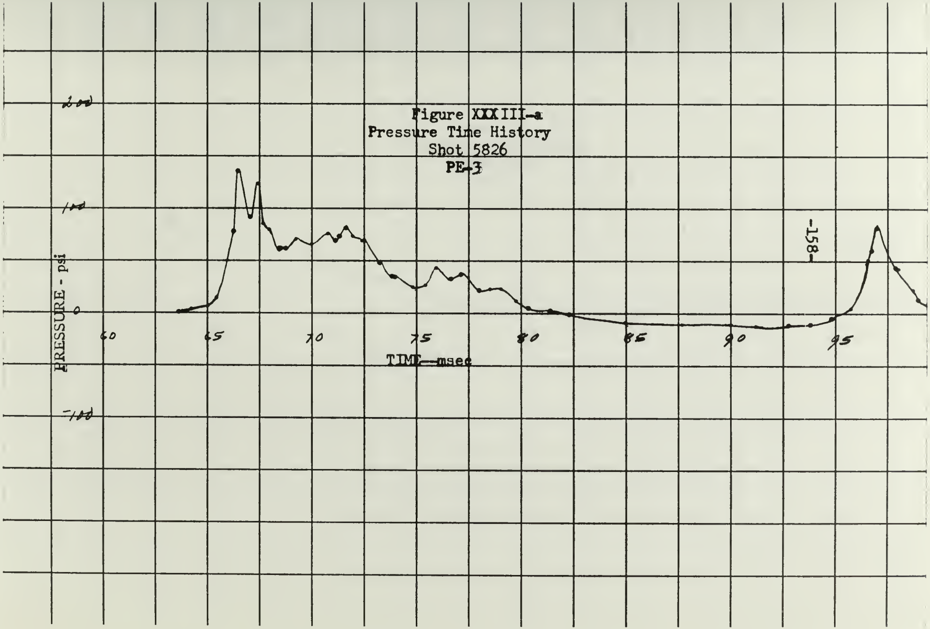


Figure XXXIII-a
Pressure Time History
Shot 5826
PE-3

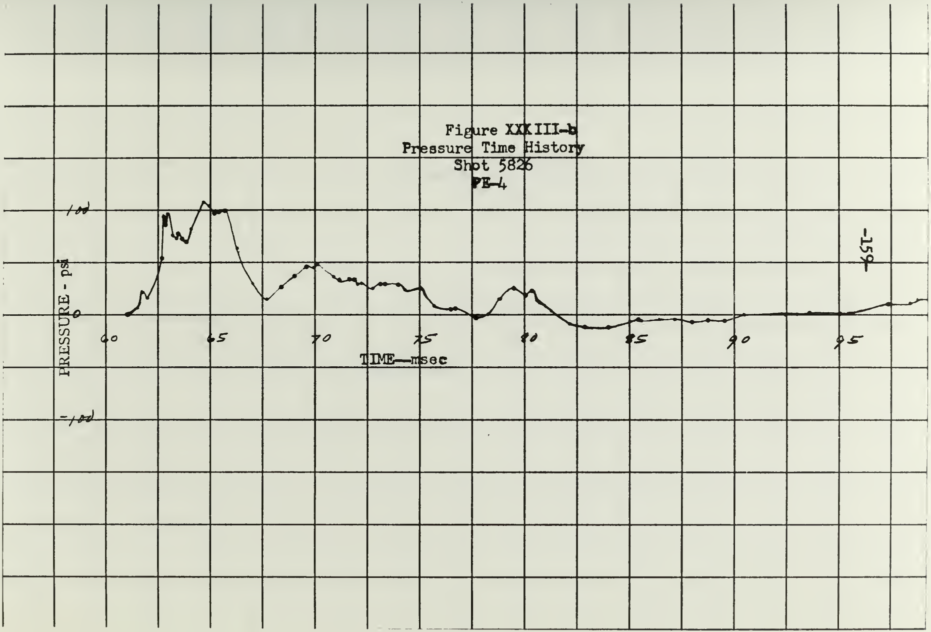


Figure XXXIII-b
Pressure Time History
Shot 5826
PE-4

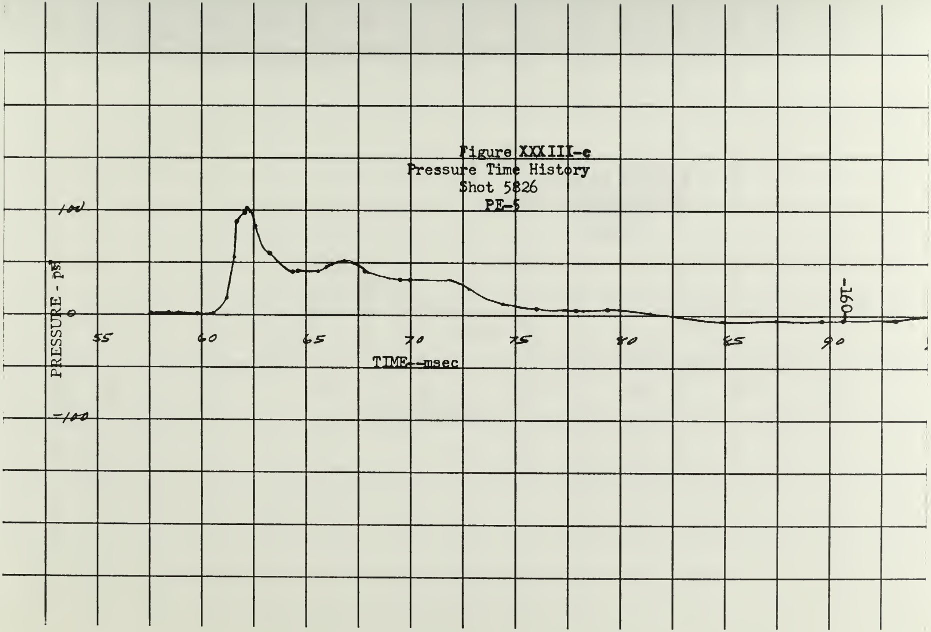


Figure XXXIII-e
Pressure Time History
Shot 5826
PE-5
PRESSURE - psi
100
0
-100
55
60
65
70
75
80
85
90
TIME--msec
-160

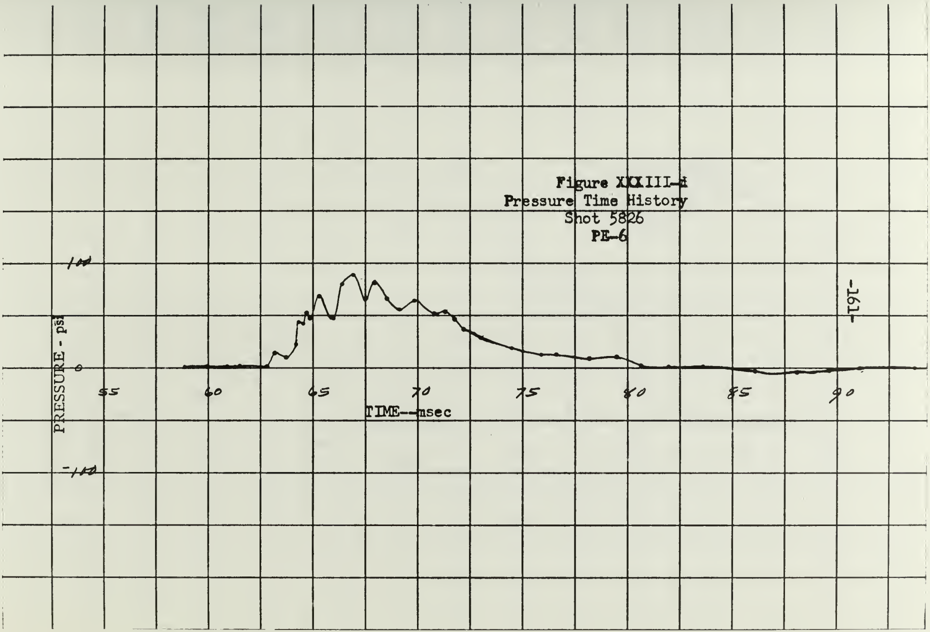


Figure XXXIII-d
Pressure Time History
Shot 5826
PE-6
PRESSURE - psi
100
0
-100
55
60
65
70
75
80
85
90
TIME--msec

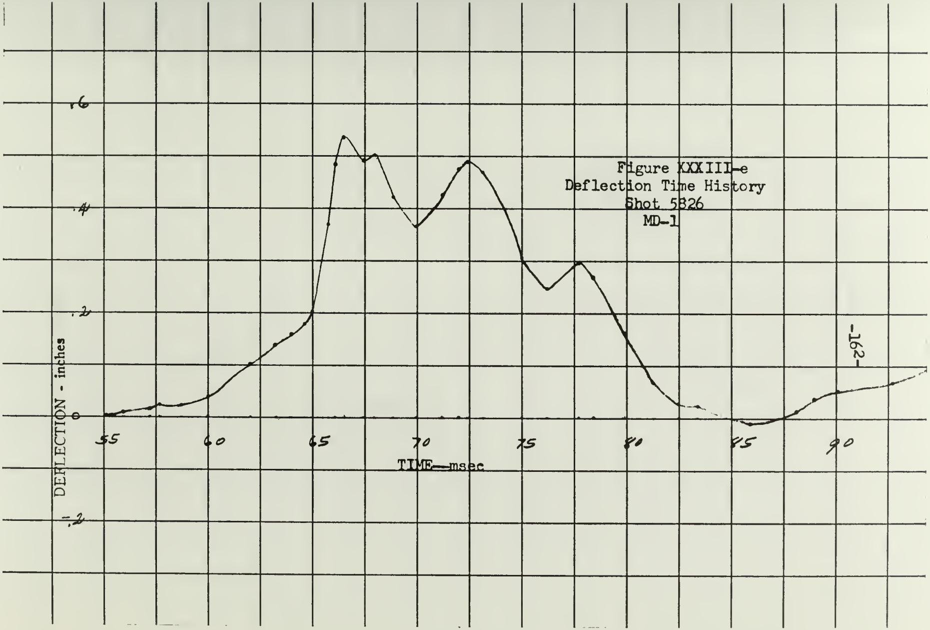


Figure XXXIII-e
Deflection Time History
Shot 5826
MD-1

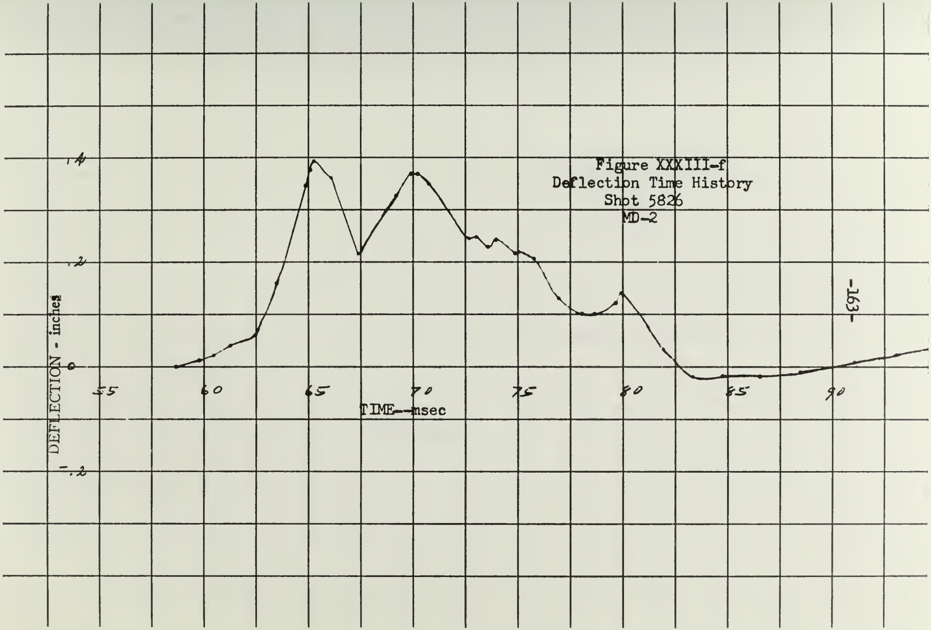


Figure XXXIII-f
Deflection Time History
Shot 5826
MD-2

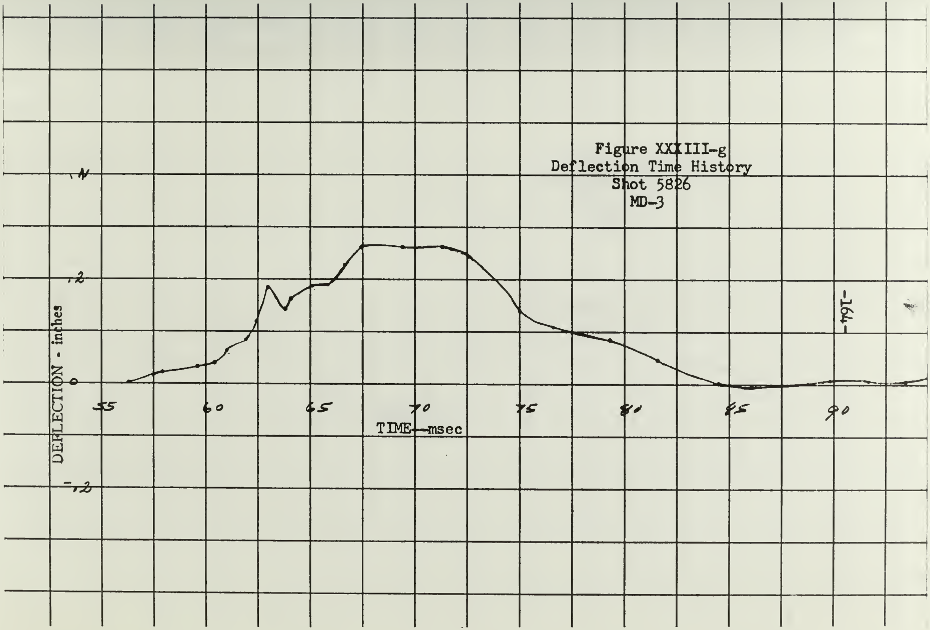


Figure XXXIII-g
Deflection Time History
Shot 5826
MD-3

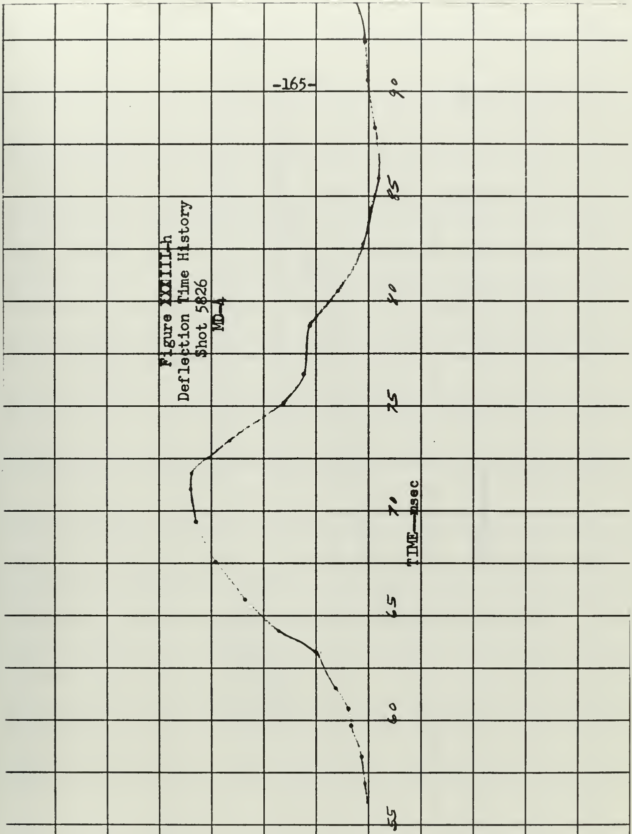


Figure XXXIII-h
Deflection Time History
Shot 5826
MD-4

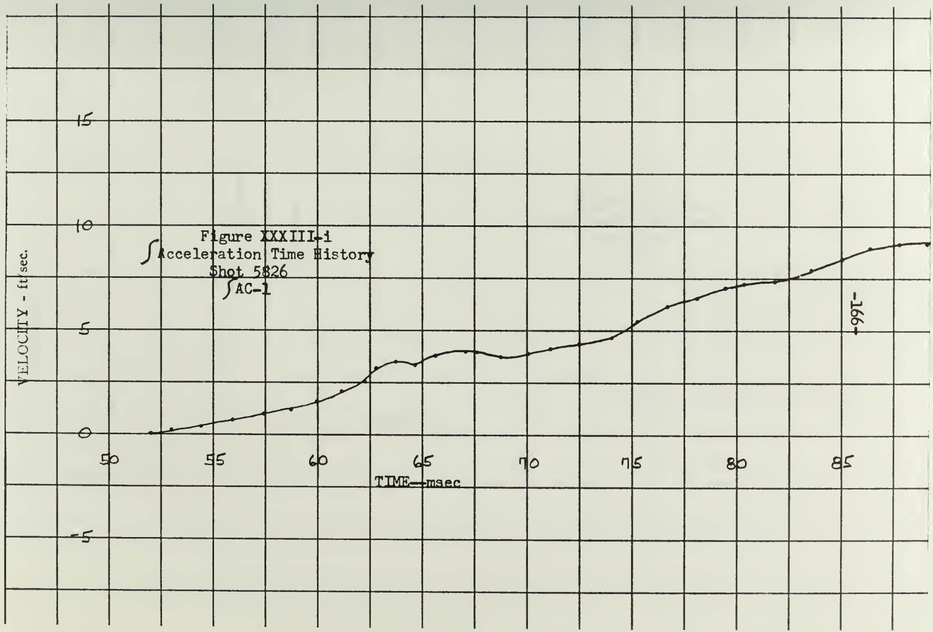


Figure XXXIII-1
∫Acceleration Time History
Shot 5826
∫AC-1

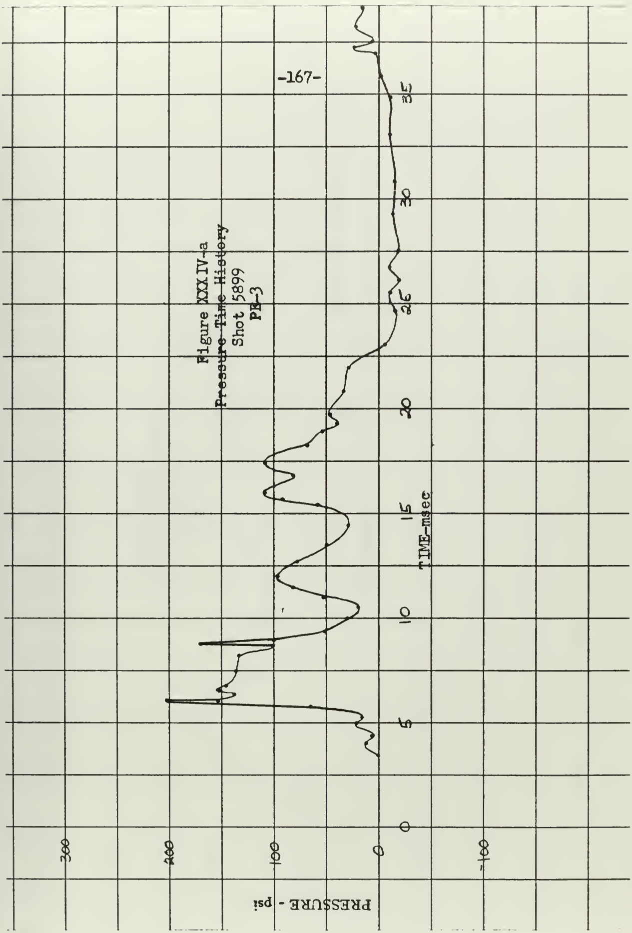


Figure XXXIV-a
Pressure Time History
Shot 5899
PE-3

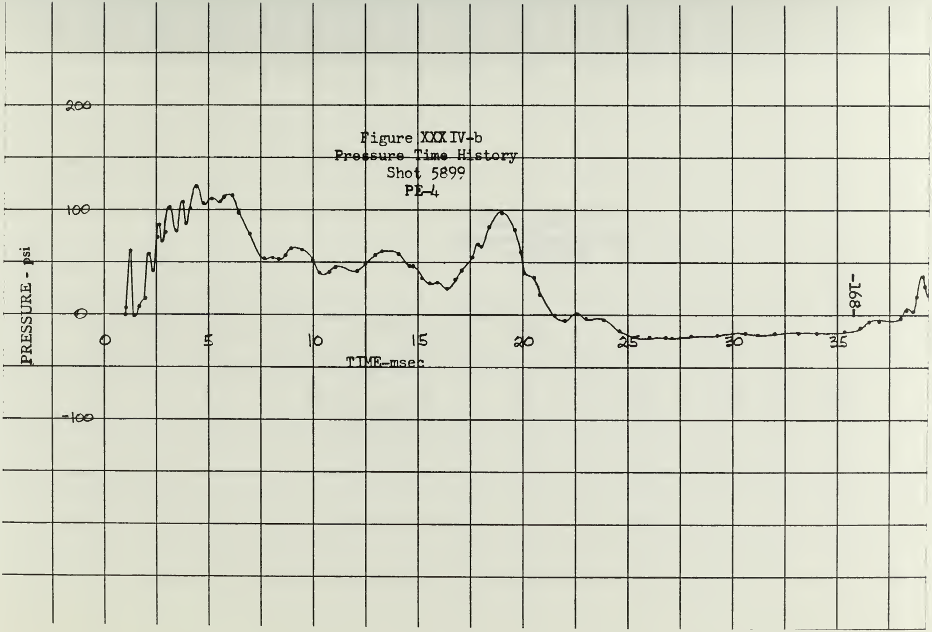


Figure XXX IV-b
Pressure Time History
Shot 5899
PE-4

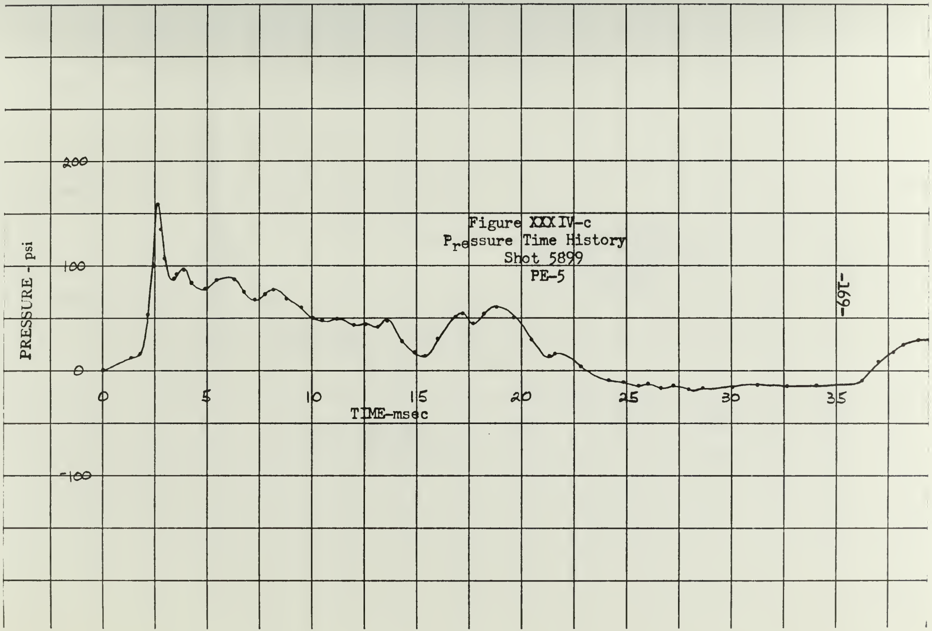


Figure XXXIV–c
Pressure Time History
Shot 5899
PE–5

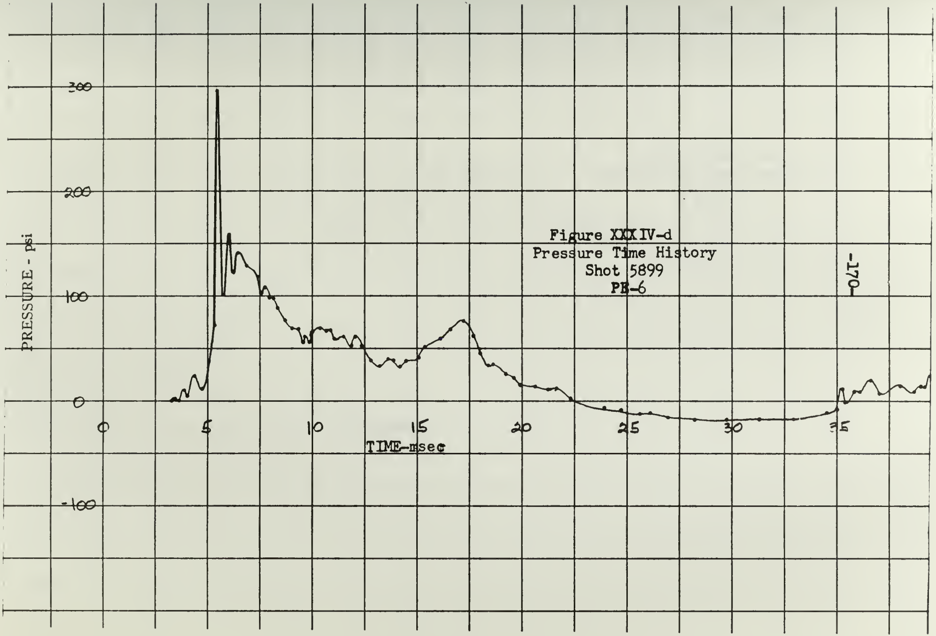


Figure XXXIV-d
Pressure Time History
Shot 5899
PB-6

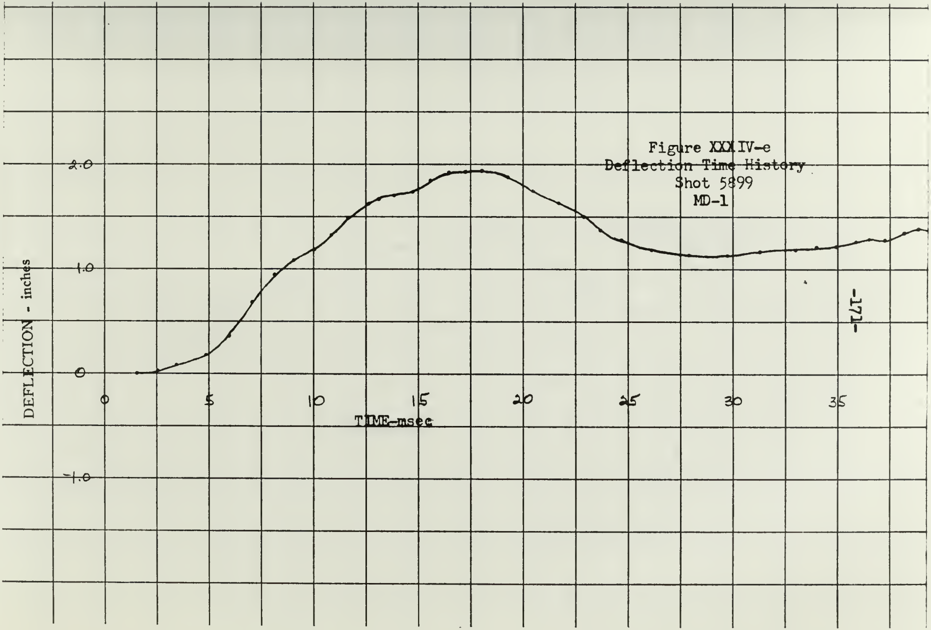


Figure XXXIV-e
Deflection Time History
Shot 5899
MD-1

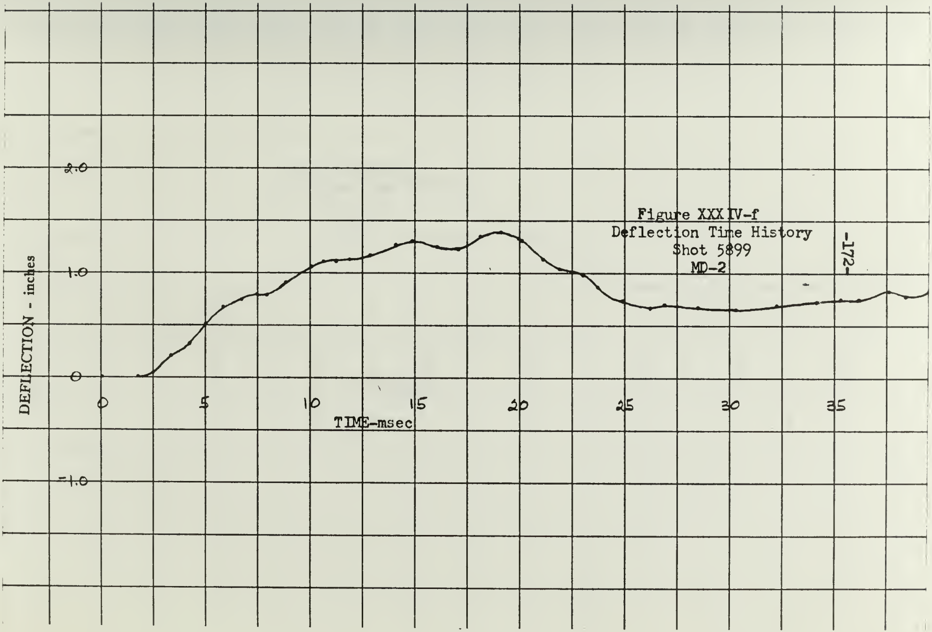


Figure XXXIV-f
Deflection Time History
Shot 5899
MD-2

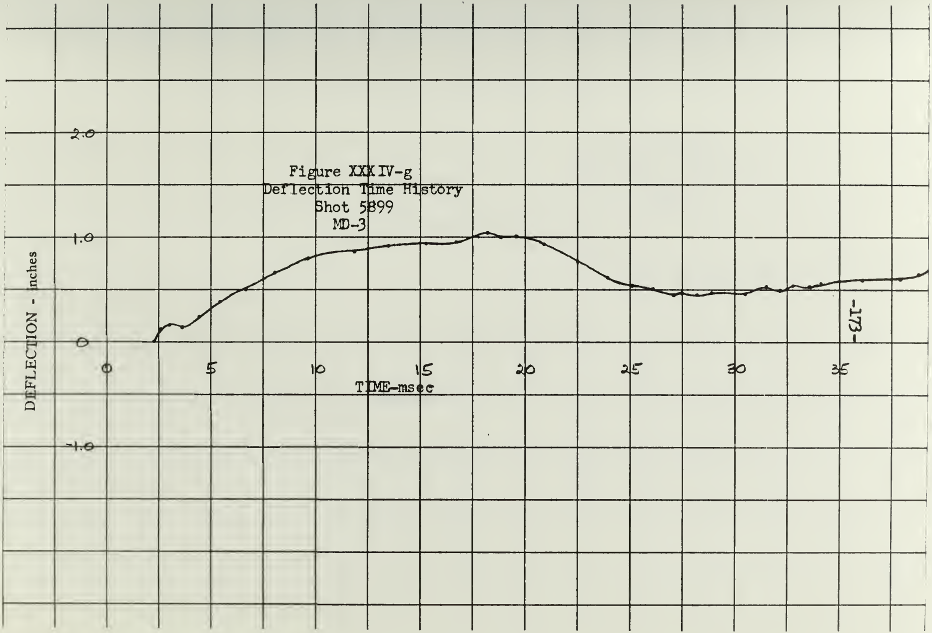


Figure XXXIV-g
Deflection Time History
Shot 5899
MD-3

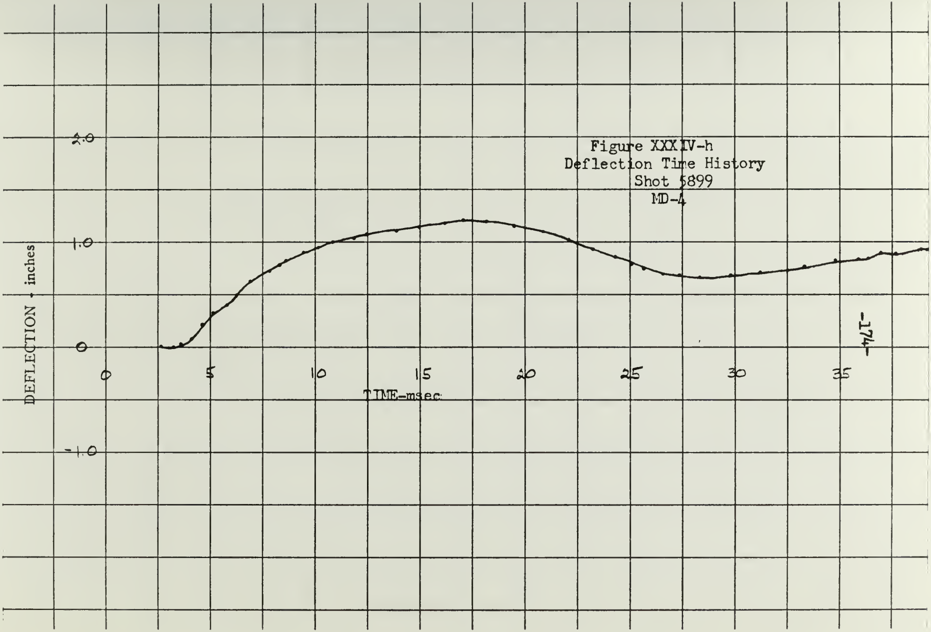


Figure XXXIV-h
Deflection Time History
Shot 5899
MD-4

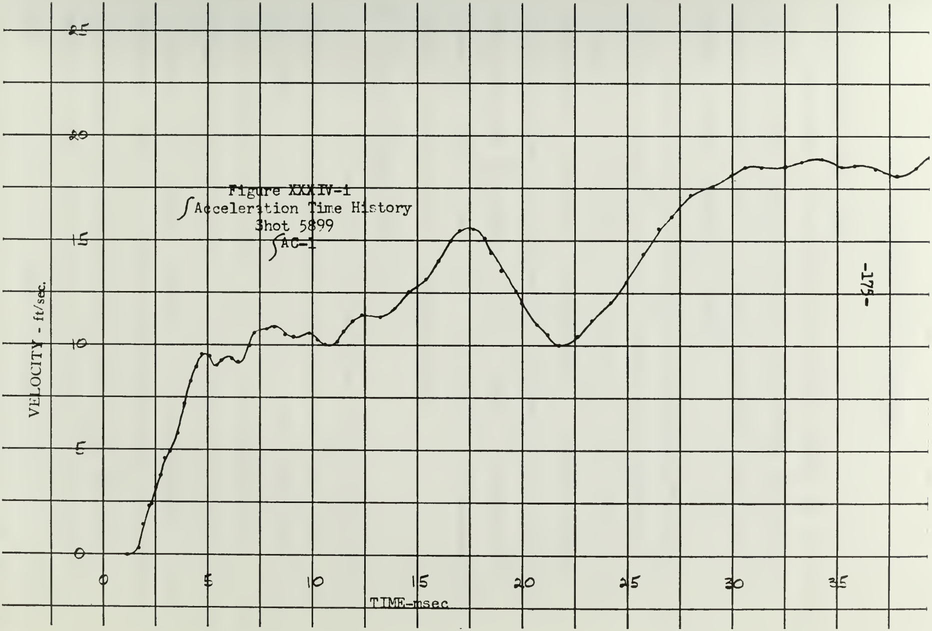


Figure XXXIV-1
∫Acceleration Time History
Shot 5899
∫AC-1

V. DISCUSSION OF RESULTS

A. Unbacked Model KG-1

This model was dropped once from a height of four feet and three times from ten feet. The results are used as a control against which to judge the relative merit of the various backing materials tested.

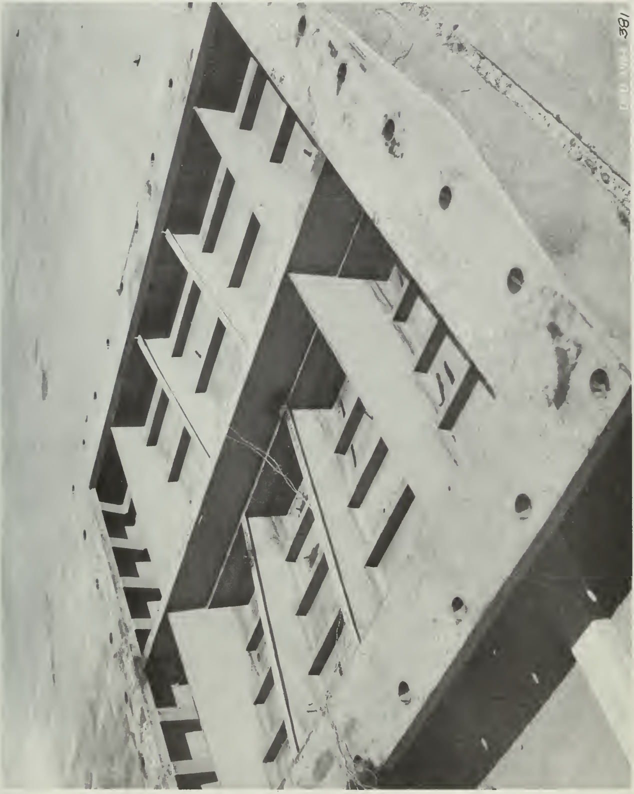
Damage to the bottom panels of plating was moderate and is shown in Tables II and IV. There was evidence of "tripping" of the transverse stiffeners near the keel and outboard ends as shown in figure XXXV. Pressure-time, deflection-time and integrated acceleration-time histories are presented in figures XXVI to XXIX. Cavitation is present in some of the drops. This will be discussed more fully in later sections of this paper.

B. Liquid Backed Model D-3

Model D-3 was first dropped four times from a height of four feet with liquid loading levels of 67°/o, 77°/o, 89°/o and 100°/o. Water was placed in the port side of the model and oil (Navy Special Fuel Oil) in the starboard side. The purpose of these tests was to determine if an optimum liquid loading level existed. Since it is not possible to detect permanent damage or plating deformation due to drops from this height, the comparison was made on the basis of maximum elastic deflections as measured by the eight MD gages. The results are shown in figures XXXVI and XXXVII. It is apparent that both the bottom plating and the tank top

Figure XXXV

Structural Damage, Model KG-1 After Three
10 Foot Drops
(Unbacked)



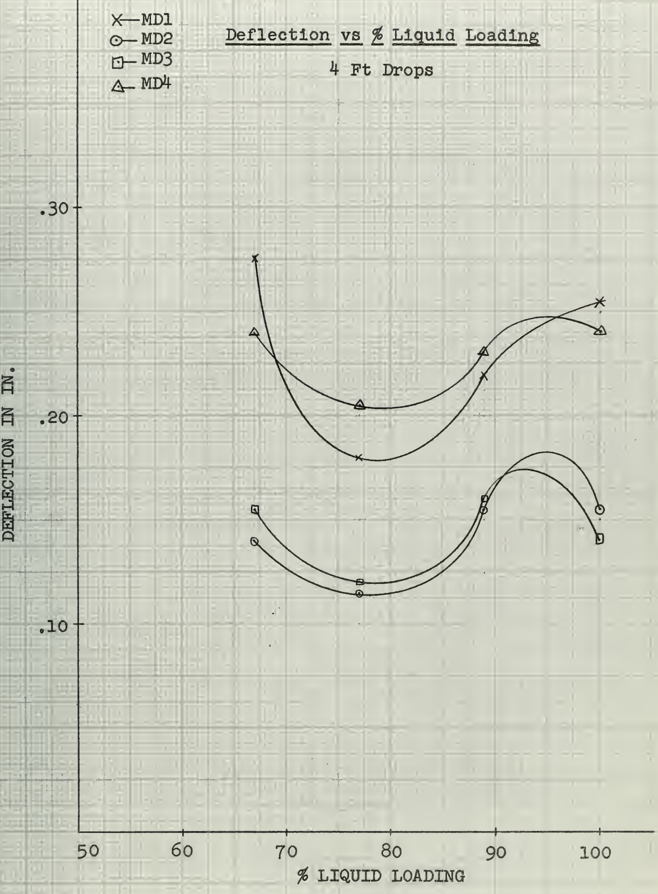


FIGURE XXXVI

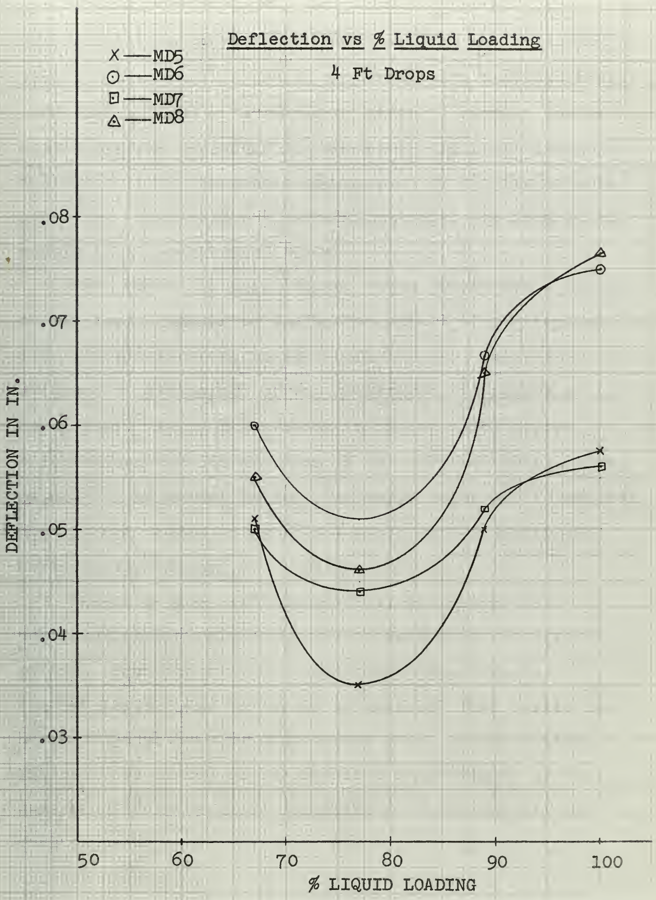


FIGURE XXXVII

undergo minimum deflections when loaded to the 77 to 80°/o level. These results are in agreement with previous tests conducted at UERD with models of aircraft carrier double bottom systems subjected to underwater explosive loadings. The 77°/o level represented 689 pounds of backing material per side. This weight of backing material was used in all models in all subsequent tests.

This model was then dropped three times from a height of ten feet. Damage to the bottom panels of plating was moderate and is shown in Tables II and IV. There was evidence of "tripping" of the transverse stiffeners as in model KG-1. As is illustrated in figure XXXVIII, the tripping was more severe than in the unbacked model. The nature of the damage to the stiffeners leads one to suspect that it was caused in part by a shock wave transmitted horizontally through the liquid.

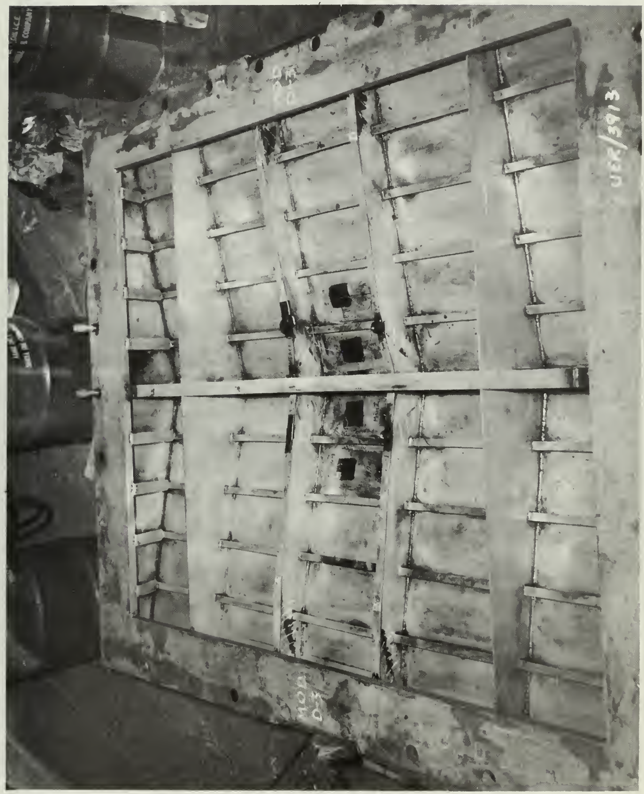
Pressure-time, deflection-time, and integrated acceleration-time histories are presented in figures XIX to XXV. From the pressure-time histories shown in figures XXIII-a and XXV-d, it is apparent that cavitation occured against the outside of the model bottom plating. The collapse of the cavity resulted in pressures of the same magnitudes as those resulting from the initial impact. This is proof that the liquid backing did not remain in contact with the bottom plating during the ten foot drops. [12]

In figures XXIII-a and XXV-d a deflection-time history is superimposed upon the pressure-time history to explain

[illegible]

Figure XXXVIII

Structural Damage, Model D-3 After Three
10 Foot Drops
(Oil and Water Backed)



the mechanism of cavitation. As the plating panel travels outward, the water is pushed away, causing the pressure to fall below the zero level. The plating begins to slow, and finally stops and begins to travel inward, creating an even greater cavity. The cavity then collapses causing a pressure peak having an extremely fast rise time. It should be noted that the plating has reversed directions and has started inward prior to the large pressure pulse. The reversal of the plating travel is, therefore, the cause, not the result of the pressure pulse.

C. <u>Sand and ML-D2 Backed Model KG-2</u>

This model was initially dropped once from a height of four feet and three times from a height of ten feet. Pressure-time, deflection-time and integrated acceleration-time histories are presented in figures XXX to XXXIV. The results of the sand side (port) and ML-D2 side (starboard) will be discussed separately.

Damage to the bottom panels of the sand side was moderate and is shown in Tables II and IV. There was evidence of "tripping" of the transverse stiffeners as in the other two models but to a lesser extent.

Damage to the bottom panels of the ML-D2 side was extremely slight and is shown in Tables II and IV. There was no evidence of "tripping" of the transverse stiffeners, although the installed ML-D2 prevented a complete inspection. The amount of cavitation present was reduced by the damping effect of ML-D2 on the plating.

D. General Comparison

As described above the experiments were conducted on the basis that no interaction exists between the two sides, port and starboard, of the model. Using this assumption, it was possible to test two backing materials in one model.

The control model, KG-1, was purposely tested with both sides unbacked to check the validity of the assumption. Figures XXXIX and XL show the permanent deflection as measured by MD gages in exactly the same location on opposite sides of the keel. The results indicate that the assumption is valid.

Figures XLI to XLVII show the permanent deflection as measured by MD gages for equivalent panels backed with the various backing materials. The following observations can be made from these figures:

a. The backing materials listed in increasing order of merit are water, oil (Navy Special Fuel Oil), sand and ML-D2.

b. The difference between oil and water is slight, and the superiority of oil is attributed to its greater viscosity or ability to absorb energy in shear.

c. Liquids do not remain in contact with the plating to be backed when the accelerations are great. Hence, their effectiveness is considered to be due almost entirely to added mass and viscous energy absorption and not due to the effects referred to in the Theory section of this paper.

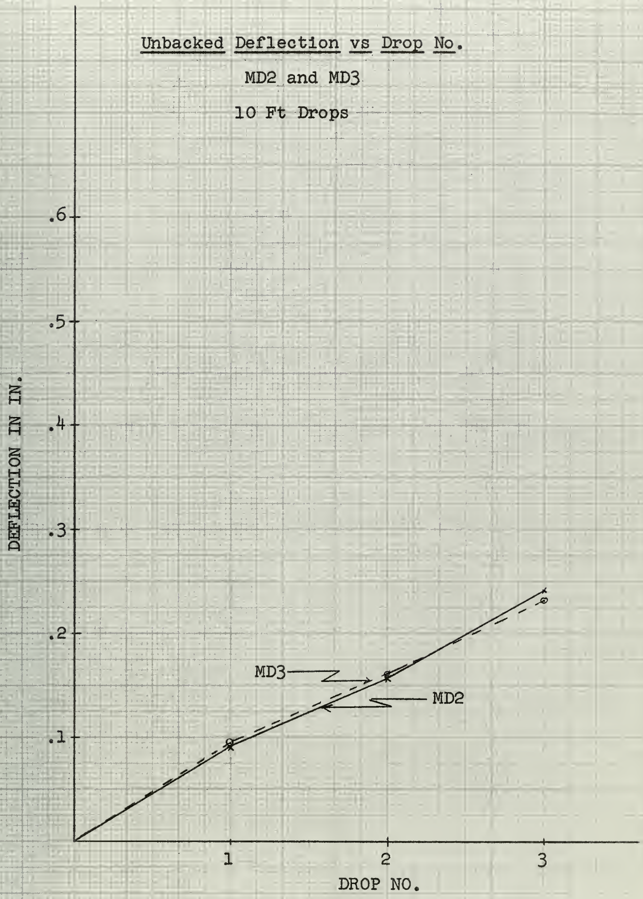


FIGURE XXXIX

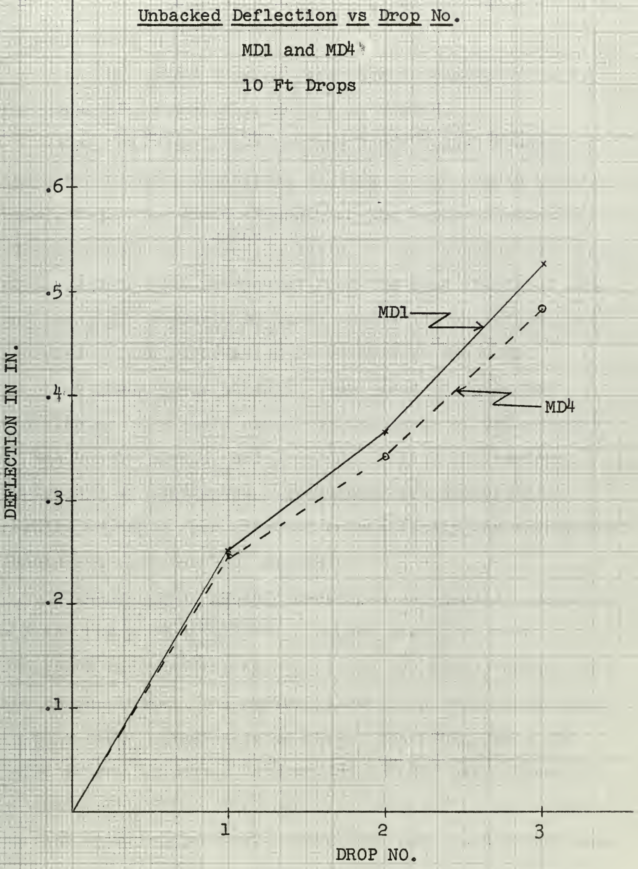

Unbacked Deflection vs Drop No.
MD1 and MD4
10 Ft Drops
DEFLECTION IN IN.
.6
.5
.4
.3
.2
.1
MD1
MD4
1
2
3
DROP NO.

FIGURE XL

d. The value of sand as a backing material is due to added mass effects.

e. ML-D2 acts as described in the Theory and is far superior to any other materials tested.

Also, one must point out the lower yield strength of the steel used in the bottom plating of the liquid backed model, D-3. The yield strength of the bottom plating of all the models is listed in Table V. The various stiffeners of all models were fabricated from the same sheets of HTS, and the yield strength of these sheets is, therefore, not included. This information is on file at the DTMB.

The lower yield strength steel used in model D-3 contributed to a small extent to the level of deformation of the bottom plating but does not explain the serious "tripping" of stiffeners. Therefore, the experimental results probably were affected only slightly and the general conclusions made are not altered.

Although model dynamic pressures are usually scaled by a factor of $\sqrt{\frac{\ell \text{ prototype}}{\ell \text{ model}}}$, impact pressures from explosive and slamming type loadings are better scaled on a one to one basis. The maximum slamming pressures recorded in full scale slamming tests aboard the USCGC Casco and USCGC Unimak (2) range between 265 and 300 psi. These are of the same order as the pressures measured by the authors in this experimental work. Since the model scantlings were scaled on a one to four basis, the model deflections are in excess of those experienced by a ship subjected to the same

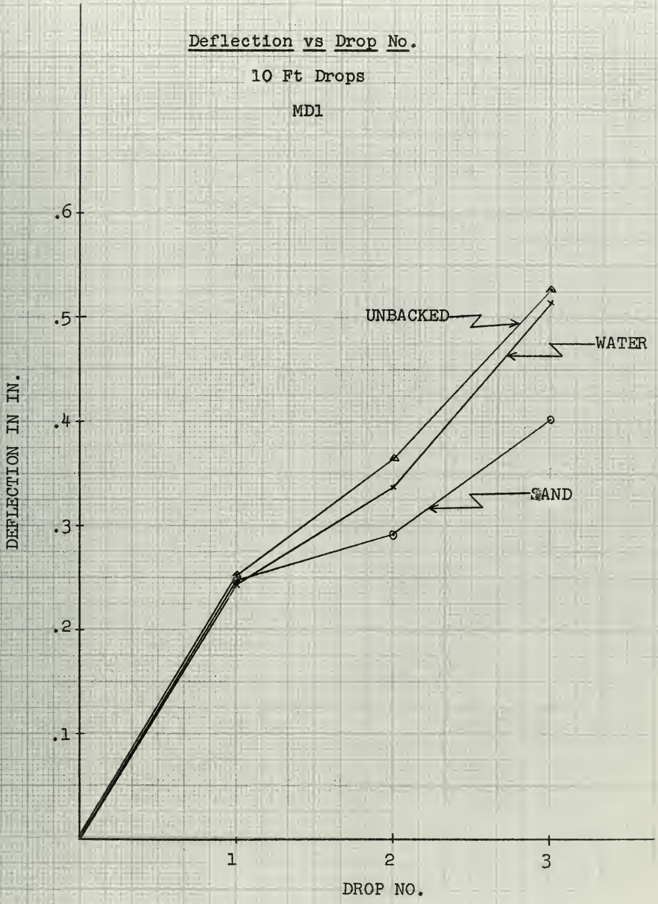

Deflection vs Drop No.
10 Ft Drops
MD1
DEFLECTION IN IN.
.6
.5
.4
.3
.2
.1
UNBACKED
WATER
SAND
1
2
3
DROP NO.

FIGURE XLI

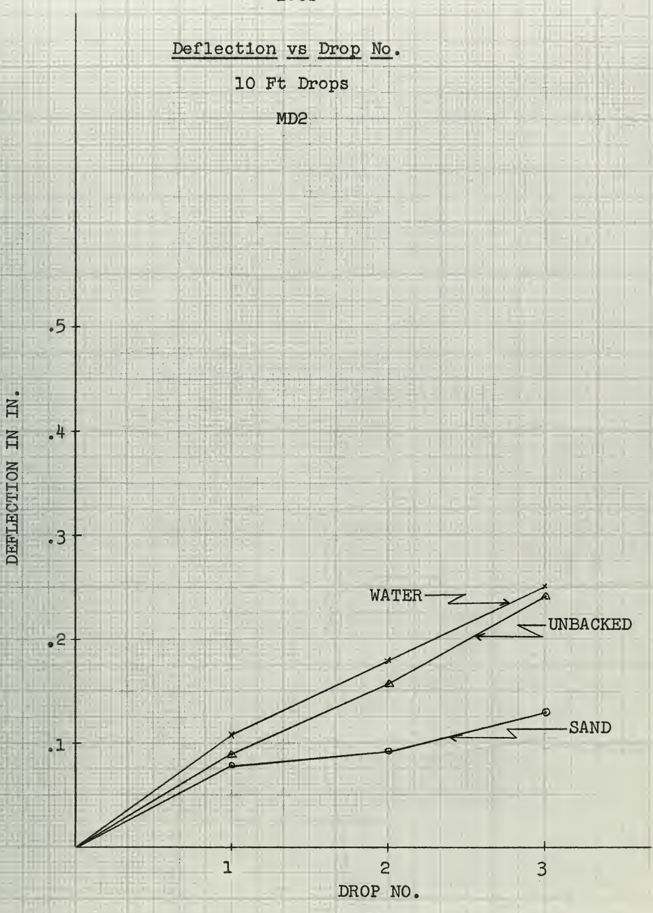

Deflection vs Drop No.
10 Ft Drops
MD2
DEFLECTION IN IN.
.5
.4
.3
.2
.1
WATER
UNBACKED
SAND
1
2
3
DROP NO.

FIGURE XLII

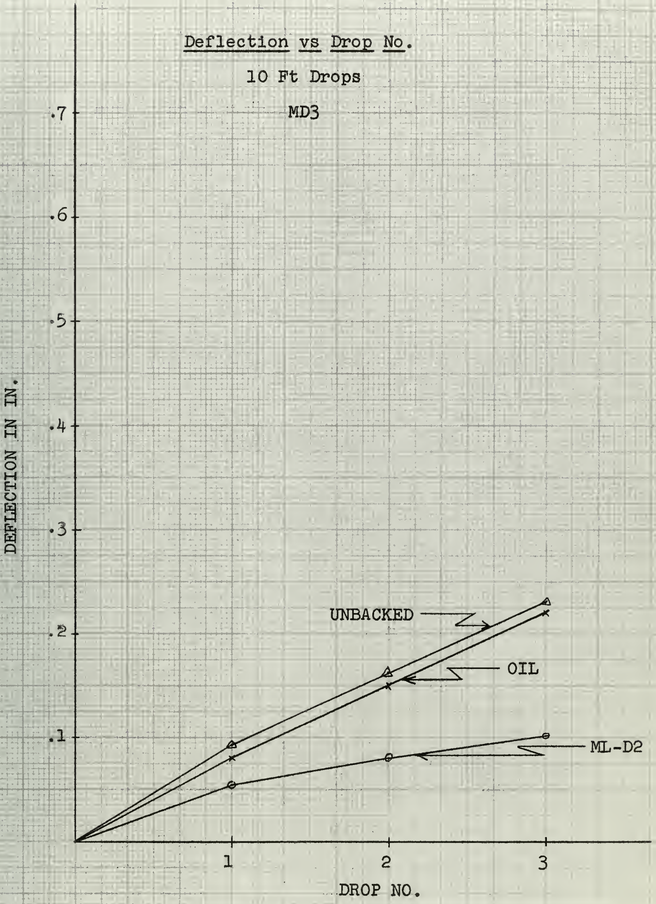


FIGURE XLIII

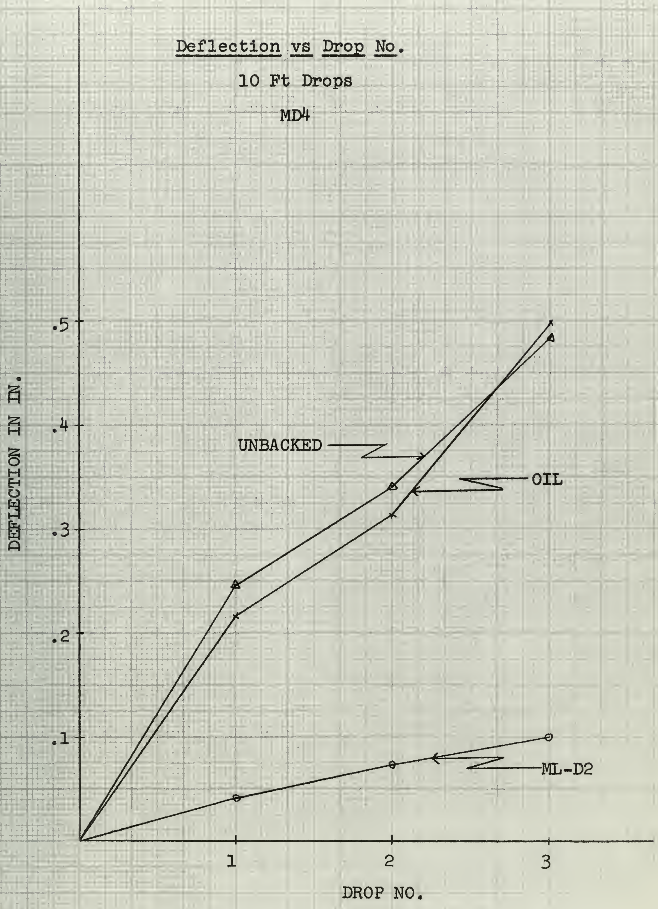

Deflection vs Drop No.
10 Ft Drops
MD4
DEFLECTION IN IN.
.5
.4
.3
.2
.1
UNBACKED
OIL
ML-D2
1
2
3
DROP NO.

FIGURE XLIV

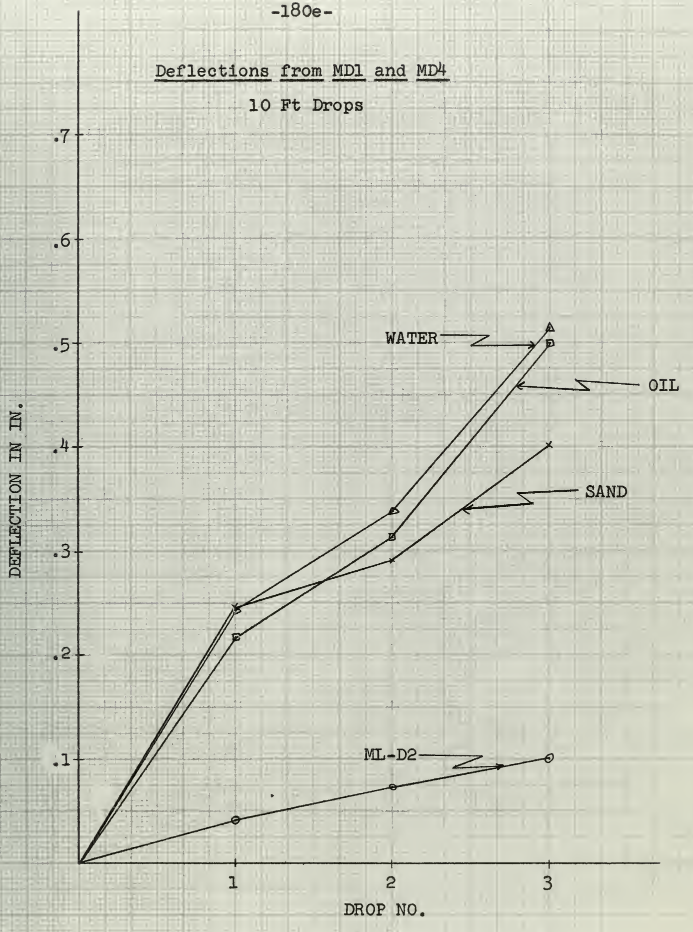

Deflections from MD1 and MD4
10 Ft Drops
.7
.6
.5
.4
.3
.2
.1
DEFLECTION IN IN.
WATER
OIL
SAND
ML-D2
1
2
3
DROP NO.

FIGURE XLV

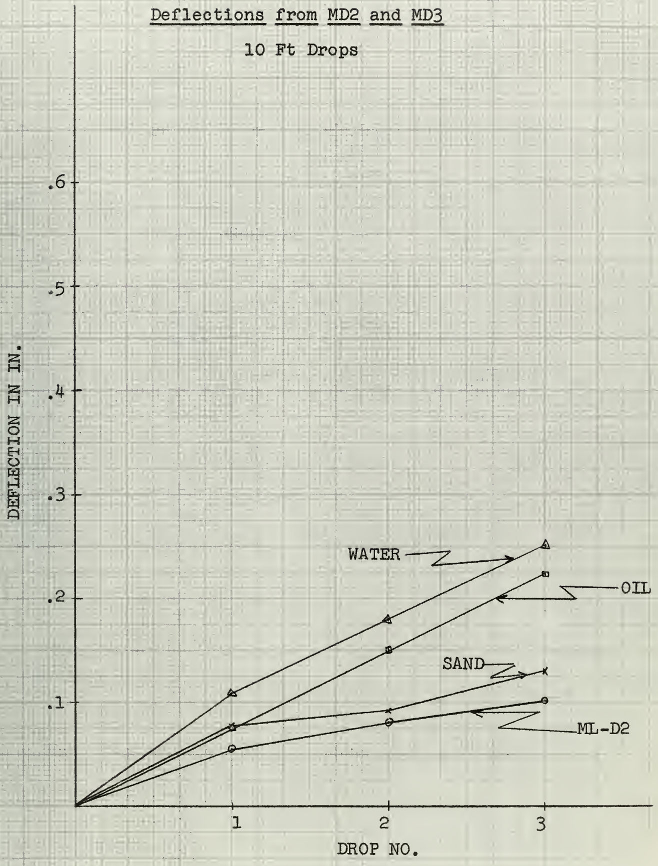
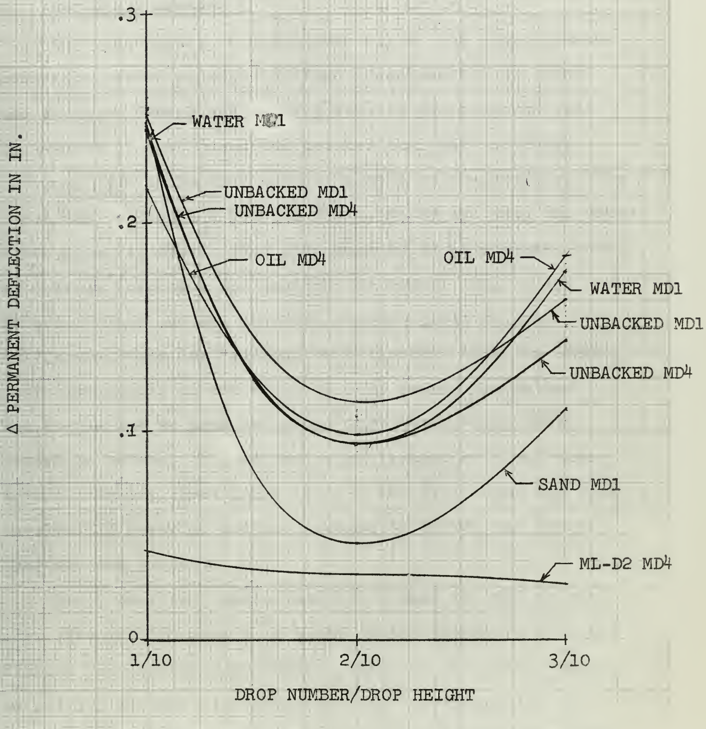

Deflections from MD2 and MD3
10 Ft Drops
DEFLECTION IN IN.
.6
.5
.4
.3
.2
.1
WATER
OIL
SAND
ML-D2
1
2
3
DROP NO.

FIGURE XLVI

Δ Permanent Deflection from MD Gages vs Drop No.

10 Ft Drops



FIGURE

XLVII

pressure. This in part explains the lack of stiffener and plating damage encountered in the full scale tests referred to above.

E. <u>Additional Testing</u>

The superiority of ML-D2 over all of the other backing materials tested prompted further experimentation. Since the level of damage was so very low, it was believed that the amount of ML-D2 used was greater than the necessary optimum. Two approaches were available to the authors. The first was to remove a portion of the ML-D2 and drop the model again from ten feet. This procedure would be repeated until an optimum thickness application was found. Due to the effect of mass and the physical support given to the stiffeners, this was believed to be greater than the thickness recommended on the basis of pure energy absorption. The second was to drop the model from twenty-five feet, loaded as before, to test the effectiveness of ML-D2 under severe slamming conditions. Due to the difficulty and cost involved in removing uniform amounts of ML-D2, the latter approach was chosen.

Model KG-2 was loaded with 689 pounds of sand on the port side and 689 pounds of ML-D2 on the starboard side and dropped from twenty-five feet. Damage to the bottom panels of plating is shown in Tables III and IV, along with the results of an unbacked model dropped from twenty-five feet by Clevenger and Melberg. [6] This latter model had been

dropped previously from heights of two, four, six, and eight feet.

Stiffener damage to the sand backed side was extensive and similar to the damage found in the unbacked model. There is little or no evidence of stiffener tripping on the ML-D2 side. This is shown in Figures XLVIII to LI.

Examination of Table III shows that both the sand and ML-D2 sides experienced less plating deformation than did the unbacked model. Here again, ML-D2 is superior to sand and extremely effective in reducing the level of damage.

The 25 foot drop tests further prove the great effectiveness of ML-D2* in preventing slamming type damage. Further information on ML-D2 may be found in BuShips Specification MIL P22581. In brief, ML-D2 is not damaged by fuel oil or sea water and is fire proof. Furthermore, the adhesive** used to bond it to the plating is as good a preservative against corrosion as paint. It has the additional advantage of not requiring periodic renewal, as is the case with paint.

The ML-D2 was removed after the 25 foot drop to facilitate examination of stiffener damage. There was evidence of some break down in the strength of the ML-D2 in the area next to the plating. This is attributed to two factors. Firstly, the deflections experienced by the ML-D2

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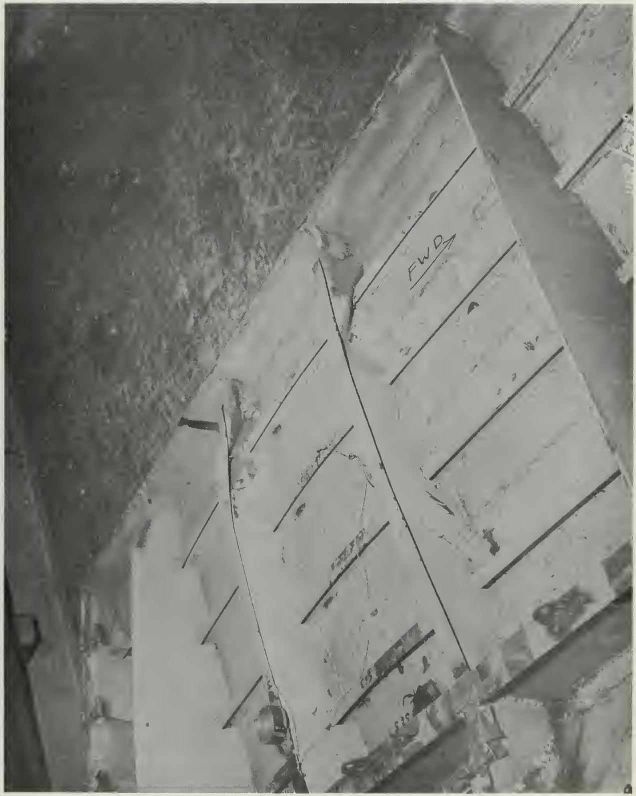
* Federal Stock Number 9G-9330-825-6649

** ML-D2 Adhesive, Philadelphia Resins Company

Figure XLVIII
Structural Damage, Unbacked Model After 25 Foot Drop



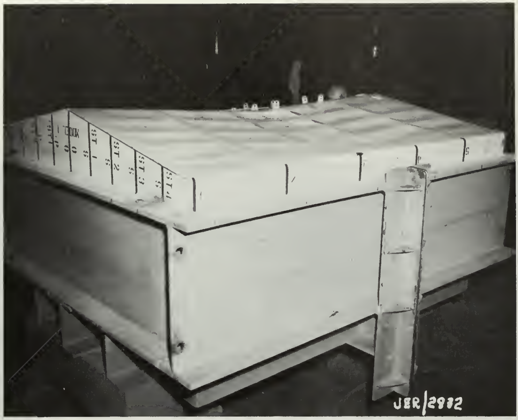


Figure XLIX
Unbacked Model After 25 Foot Drop

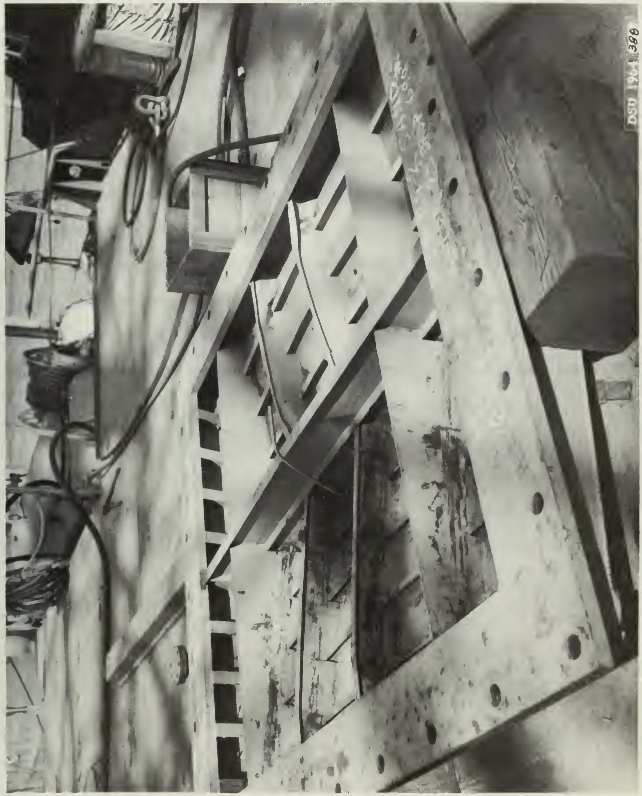
Figure L
Model Backed by Sand and ML-D2 After 25 Foot Drop

Figure LI

Structural Damage, Model Backed by Sand and ML-D2
After 25 Foot Drop

Figure LI-a

Structural Damage, Model Backed by Sand and ML-D2
After 25 Foot Drop



in the 25 foot drop were extremely severe. Deflections of this magnitude would not be experienced in actual use aboard ship. Secondly, the layer next to the plating was not bonded with a layer of adhesive. This was done to permit easy removal after testing. The fit achieved without adhesive was quite tight. All subsequent layers were completely bonded. By not being bonded to the plating, the ML-D2 was "scuffed" during the test, and hence weakened. U. S. Navy installation instructions for ML-D2* point out the danger of "scuffing."

The damage to the ML-D2 was due to the extreme conditions encountered during the 25 foot drop and should not limit its use in actual ships. ML-D2 has been installed in the bow area and sonar domes of destroyers for some time with no evidence of break down or loss of strength.

*BuShips Notice 9390

VI. CONCLUSIONS

1. A backing material must remain in contact with the plating it is to protect if it is to be effective.

2. When accelerations are small, a liquid loading level of approximately 77 to 80°/o results in minimum elastic deflection of both the tank top and bottom plating. This agrees with the results of explosive loading tests conducted on models of aircraft carrier double bottom systems.

3. Cavitation occurs when panel vibration is excessive, resulting in a pressure reloading of the bottom plating after the initial impact loading. This contributes to the final permanent deformation of the plating.

4. Visco-elastic materials such as ML-D2 offer excellent protection against slamming damage. They absorb great amounts of energy, afford physical support to stiffeners and decrease the amplitude of vibration of the panels of plating.

5. Sand offers some protection against slamming damage due to its mass.

6. Liquid backing is relatively ineffective in preventing major slamming damage when it cannot be made to remain in contact with the bottom plating. This occurs when accelerations are great.

7. Not enough drops were made from 10 feet to prove or disprove the hypothysis that the deformation will reach a limiting value after repeated drops.

VII. RECOMMENDATIONS

1. Install visco-elastic material in the forward areas of ships that experience severe slamming motions and resulting slamming damage.

2. Conduct model tests to determine the optimum thickness of visco-elastic material to apply. In the absence of experimental data, an application of 4 to 6 times the plating thickness is recommended.

3. Investigate the possibility of using materials such as sand on top of the visco-elastic material to take advantage of their mass effect.

4. Engineers of ships having fuel or water tanks in the area where slamming damage is most likely to occur should keep these tanks approximately 80% full if this does not create stability problems. The liquid in a deep tank is more likely to remain in contact with the bottom plating than is the liquid in a shallow tank.

5. The placing of tanks in the forward area of new designs solely for the purpose of reducing slamming damage by liquid backing is not recommended.

Appendix A

Table II.

PERMANENT DEFORMATION IN INCHES AFTER
THREE 10 FT DROPS
(ACTUAL MEASUREMENTS)

		MODEL	
LOCATION	D-3	KG-1	KG-2
BACKING MATERIAL	OIL	UNBACKED	ML-D2
2½D STBD	.41	.34	-.02
1½D STBD	.29	.31	.00
½D STBD	.11	.16	.02
2½F STBD	.70	.51	.09
1½F STBD	.44	.39	-.02
½F STBD	.21	.16	.04
2½H STBD	.40	.35	.00
1½H STBD	.34	.31	.01
½H STBD	.17	.17	.00
BACKING MATERIAL	WATER	UNBACKED	SAND
2½D PORT	.47	.29	.27
1½D PORT	.31	.31	.25
½D PORT	.16	.20	.08
2½F PORT	.84	.43	.45
1½F PORT	.27	.40	.35
½F PORT	.26	.17	.11
2½H PORT	.50	.28	.04
1½H PORT	.32	.23	.16
½H PORT	.17	.19	.30

Table III.

DEFLECTIONS IN INCHES OF BACKED MODELS COMPARED WITH UNBACKED MODELS DROPPED FROM 25'
(ACTUAL MEASUREMENTS)

	BACKING	
LOCATION	SAND	UNBACKED
½D	.66	1.604
1½D	1.02	1.868
2½D	1.09	1.797
½F	.90	2.795
1½F	1.61	2.946
2½F	1.82	2.087
½H	.53	1.745
1½H	1.00	1.873
2½H	1.10	.877

	BACKING	
LOCATION	ML-D2	UNBACKED
½D	.38	1.718
1½D	.46	1.285
2½D	.64	1.954
½F	.60	2.943
1½F	.88	2.293
2½F	1.22	2.174
½H	.32	1.470
1½H	.34	1.963
2½H	.39	.875

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Table IV.

PERMANENT DEFLECTIONS AS READ
FROM MD GAGES
AFTER ONE 4' DROP AND
THREE 10' DROPS

	UNBACKED	OIL	WATER	SAND	ML-D2
MD1	.556		.624	.443	
MD2	.262		.318	.141	
MD3	.269	.292			.121
MD4	.512	.582			.127

DEFLECTION FOR
25 FT DROP

	SAND	ML-D2
MD1	1.31	
MD2	.78	
MD3		.52
MD4		.83

[illegible]

[illegible]

[illegible]

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Table V.

YIELD STRESS OF MODEL BOTTOM PLATING IN PSI
(.2% OFFSET)

MODEL	PORT	AVERAGE YIELD STRESS
D-3	Port	37,050
D-3	Stbd	35,100
KG-1	Port	40,488
KG-1	Stbd	40,488
KG-2	Port	39,824
KG-2	Stbd	39,824

[illegible]

[illegible]

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REVISIONS				
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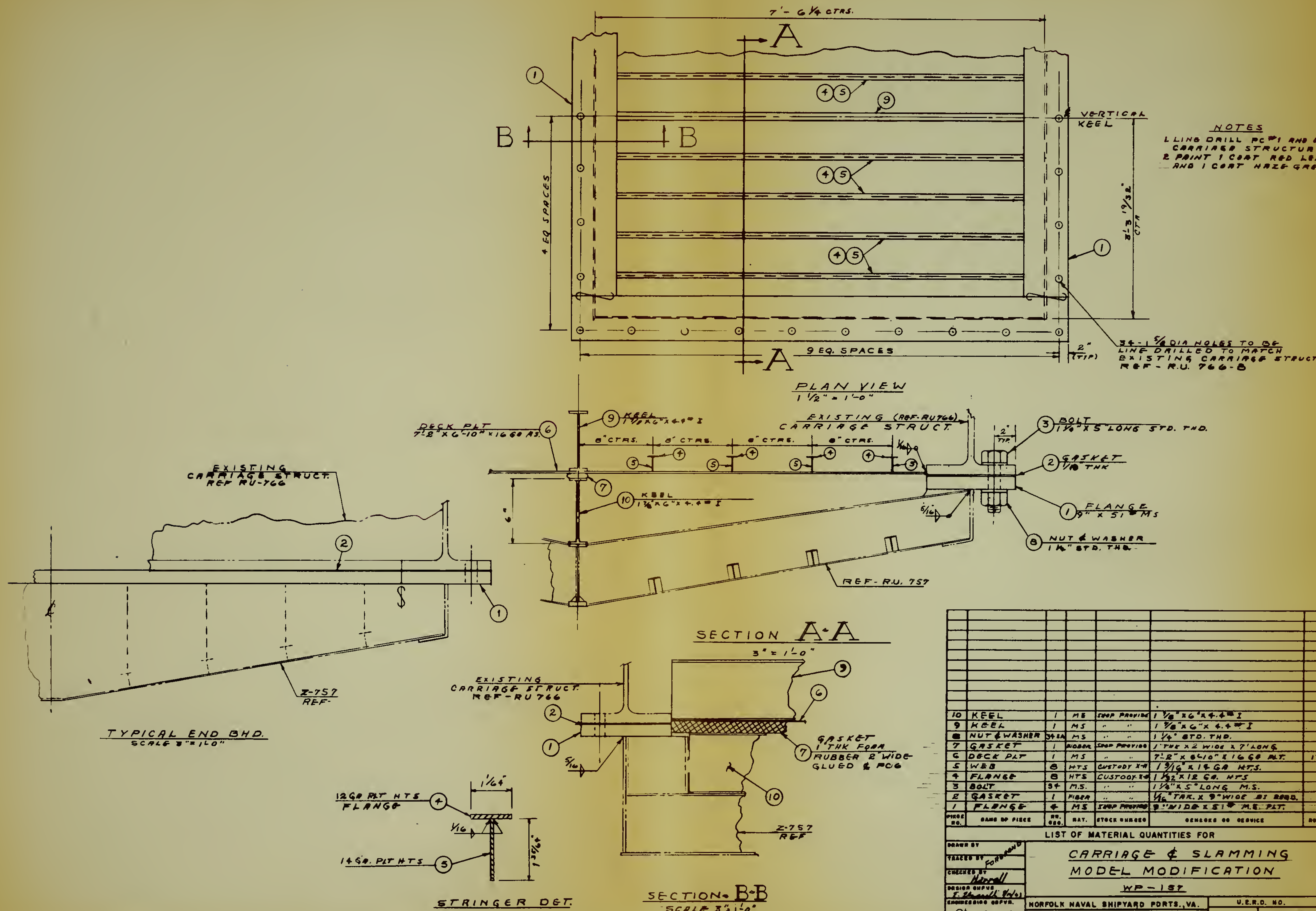


PIECE NO.	NAME OF PIECE	NO. REQ.	MAT.	STOCK NUMBER	REMARKS OR SERVICE	ROUTING
10	KEEL	1	MS	SHOP PROVIDE	1 1/8" x 6" x 4.4# I	"
9	KEEL	1	MS	" "	1 1/8" x 6" x 4.4# I	"
8	NUT & WASHER	34 EA	MS	" "	1 1/4" STD. THD.	"
7	GASKET	1	RUBBER	SHOP PROVIDE	1" THK x 2 WIDE x 7' LONG	"
6	DECK PLT	1	MS	" "	7'-2" x 6'-10" x 16 GA PLT.	17-H
5	WEB	8	HTS	CUSTODY X-H	1 5/16" x 14 GA HTS.	"
4	FLANGE	8	HTS	CUSTODY X-H	1 1/32" x 12 GA. HTS	"
3	BOLT	34	M.S.	" "	1 1/8" x 5" LONG M.S.	"
2	GASKET	1	FIBER	" "	1/16" THK. x 9" WIDE AS REQD.	"
1	FLANGE	4	MS	SHOP PROVIDE	9" WIDE x 51" M.S. PLT.	"

LIST OF MATERIAL QUANTITIES FOR

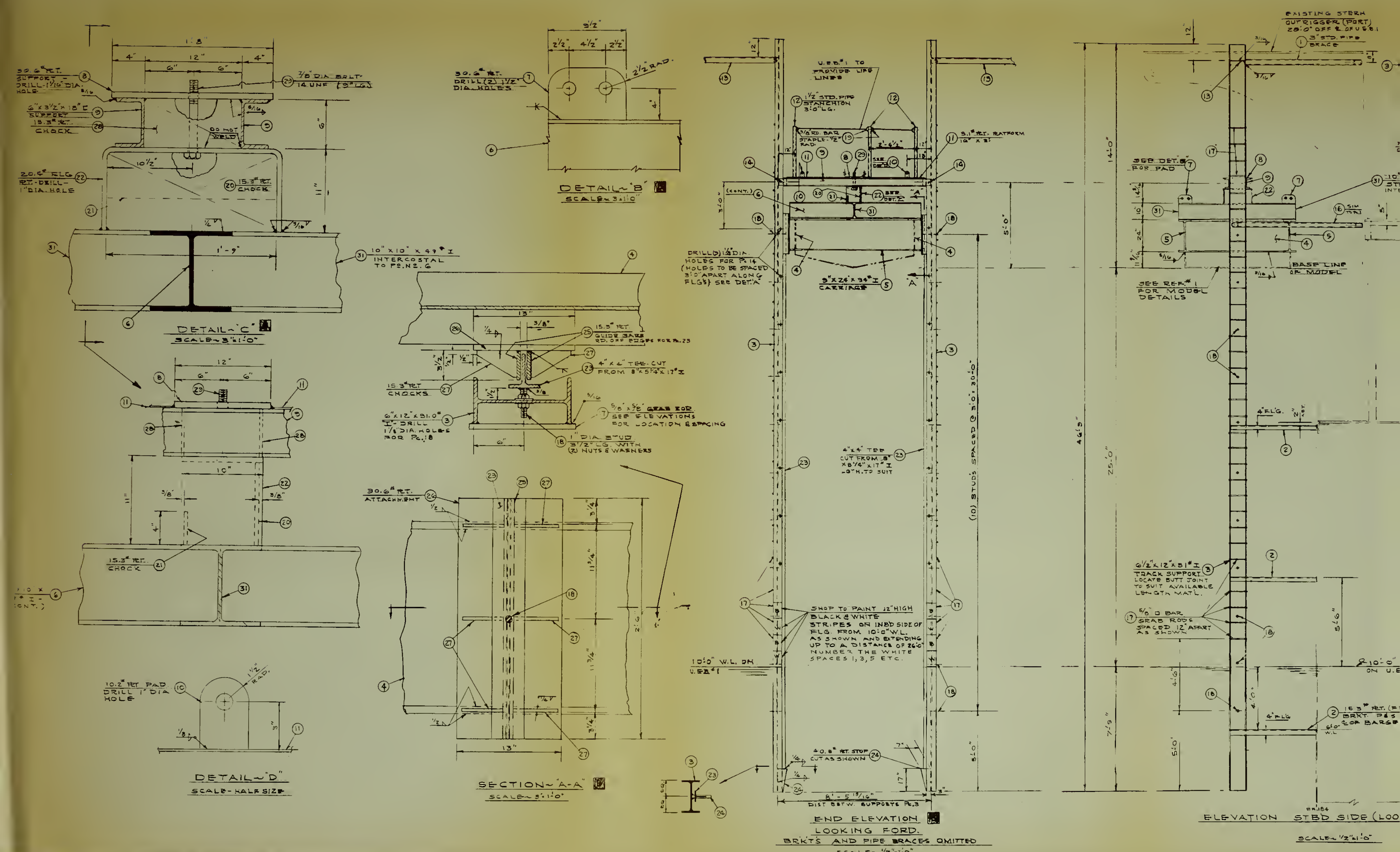
CARRIAGE & SLAMMING MODEL MODIFICATION

WP-157

NORFOLK NAVAL SHIPYARD PORTS., VA.

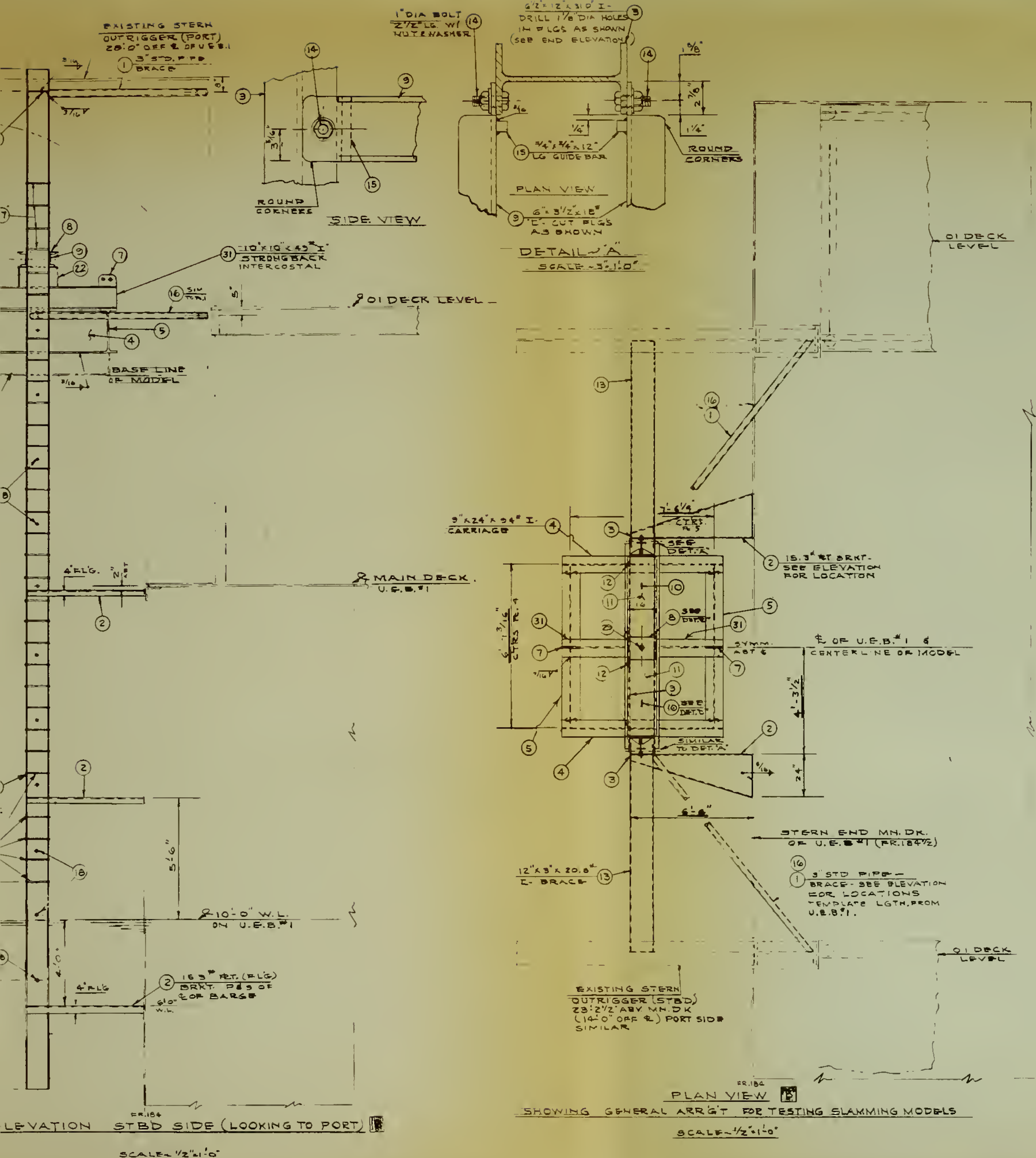
DRAWN BY	TRACED BY	CHECKED BY	DESIGN SUPVR	ENGINEERING SUPVR.	BRANCH SUPVR	APPROVED DIVISION HEAD	PROJECT OFFICER	DATE
	Forehand	Harrell	[illegible]		[illegible] 1/17/63	[illegible]		[illegible]

U.E.R.D. NO.		REV.
WP-157	R.U. NO. 804	A
SCALE: NOTED	SHEET 1 OF 1	



DETAIL~"C"
SCALE~3"=1'-0"
DETAIL~"B"
SCALE~3"=1'-0"
DETAIL~"D"
SCALE-HALF SIZE
SECTION~"A-A"
SCALE~3"=1'-0"
END ELEVATION
LOOKING FORD.
BRKT'S AND PIPE BRACES OMITTED
SCALE~1/2"=1'-0"
ELEVATION STBD SIDE (LOO
SCALE~1/2"=1'-0"

REV. NO	ZONE	DESCRIPTION	APPROVED BY	DATE
B		PLAN ALTERED TO SHOW MODEL ROTATED 90°. LIST OF MAT'L. ALTERED TO SUIT.	Harrell	10/17/61



GENERAL NOTES

1. BEFORE MODEL #1 (SHOWN ON REF. 1) IS INSTALLED ON CARRIAGE SHOP IS TO INSTALL Pc. 30, A 20.4# PT. AT BOTTOM OF CARRIAGE Pcs 4 & 5 SO AS TO TEST PROOF OPERATION OF RIG.
2. SHOP TO APPLY A COAT OF GREASE ON WEB OF "TEE" BAR GUIDE Pc. 23
3. EXTRA BOLTS Pc 29 TO BE DELIVERED TO U.E.B.#1.

REFERENCE PLAN

1. SLAMMING MODEL (1/4 SCALE OF PROTOTYPE) R.U. No. 757

PIECE NO	NAME OF PIECE	NO REQ	MAT	STOCK NUMBER	REMARKS OR SERVICE	ROUTING
31	STRONG BACK	2	M.S.	SHOP PROVIDE	10" x 10" x 49# I (ABT. 4'-3" LG.)	
30	TEST PT	1	M.S.	SEE NOTE 1, SHOP PROVIDE	6'-8" x 7'-7" x 20.4# PT.	//
29	SUPPORT BOLT	6	M.S.	SHOP PROVIDE	7/8" DIA. 14 UNF. 9" LONG	
28	CHOCK	2	M.S.		CUT FROM 6" x 12" x 15.3# PT	
27	CHOCKS	12	M.S.		CUT FROM 9" x 5 5/8" x 15.3# PT	
26	ATTACHMENT PT.	2	M.S.		15" x 2'-6" x 30.6# PT.	
25	GUIDE BARS	4	M.S.		5 1/2" x 2'-6" x 16.3# PT	
24	STOP	2	M.S.		CUT FROM 7" x 17" x 40.8# PT.	
23	"T" BAR GUIDE	2	M.S.		[illegible]	
22	FLG. PT.	1	M.S.		10" x 3'-9" x 20.4# PT FLG.	
21	CHOCK	1	M.S.		CUT FROM 4" x 1'-9" x 15.3# PT	
20	CHOCK	1	M.S.		CUT FROM 10 1/2" x 1'-9" x 15.3# PT	
19	STAPLES	4	M.S.		5/8" DIA RD. BAR - 1/2" RAD.	
18	STUD BOLTS	22	M.S.		1" DIA - 5 1/2" LG W/(2) NUTS [illegible]	
17	GRAB RODS	62	M.S.		5/8" Ø RD. BAR - 13" LG	
16	PIPE BRACE	2	M.S.		3" STD. PIPE - ABT. 18'-0" LG	
15	GUIDE BAR	4	M.S.		3/4" x 3/4" x 12" - SEE DET. A	
14	BOLT W/NUT	4	M.S.		1" DIA. BOLT - 2 1/2" LG W/WASHER	
13	C-BRACE	2	M.S.		12" x 3" x 20.8# C - ABT. 9'-5 1/2" LG	
12	STANCHION	8	M.S.		1 1/2" STD PIPE - 3'-0" LG	
11	PLATFORM	2	M.S.		CUT FROM 16" x 3'-3 1/2" x 5.1# PT.	
10	HANDLING PAD	2	M.S.		CUT FROM 5" x 6 1/2" x 10.2# PT	
9	SPREADER	2	M.S.		6" x 3 1/2" x 18# C - ABT. 8'-7" LG	
8	SUPPORT PT.	1	M.S.		CUT FROM 12" x 20" x 30.6# PT	
7	LIFTING PAD	2	M.S.		CUT FROM 6 1/2" x 9 1/2" x 30.6# PT	
6	STRONGBACK	1	M.S.	SHOP PROVIDE	10" x 10" x 49# I - 7'-6" LG	
5	CARRIAGE	2	M.S.	IN CUSTODY	24" x 9" x 94# I - 6'-7" LG	
4	CARRIAGE	2	M.S.	IN CUSTODY	24" x 9" x 94# I - 6'-9" LG	
3	TRACK SUPPORT	2	M.S.	SHOP PROVIDE	12" x 6 1/2" x 31.8# I - ABT. 46'-5" LG	
2	BRACKETS	6	M.S.	"	CUT FROM 28" x 6'-6" x 15.3# PT.	
1	PIPE BRACE	2	M.S.	[illegible]	3" STD PIPE - ABT. 12'-7" LG	

LIST OF MATERIAL QUANTITIES FOR ONE TESTING RIG

CARRIAGE AND GUIDE TRACK

(WP-157)

BUREAU OF STRUCTURAL MECHANICS LAB. D T M B, PORTSMOUTH, VA

R.U. NO. 766 REV B

DRAWN BY: [illegible] TRACED BY: [illegible] CHECKED BY: Harrell DESIGN SUPVR: Harrell

SCALE: AS NOTED SHEET 1 OF 1